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EDDY CURRENT SCANNING REPORT

FNAL-3RDHARMONIC CAVITIES #7-8

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1 INTRODUCTION

As part of Fermilab's effort to fabricate 3rd harmonic module, niobium blanks as delivered by Wah-Chang, are being scanned with the eddy-current technique to reveal inclusions or other sub-surface defects. The results of the scanning of 3rd harmonic sheets 163-204 are reported in this note. Also included are the results of a simple visual inspection of the surface. The report discusses some of the defects detected and concludes with recommendations regarding the use of the blanks for the subsequent cavity fabrication.

To accommodate the smaller samples for the Fermilab 3.9 GHz cavities a special sample-holder¹ had to be fabricated (see Figure 1). The SNS cavities were fabricated from much larger Nb sheets. The figure below shows how the discs were mounted into the sample-holder, given their reduced diameter of 3.625 ". As shown in the figure the discs were more or less centered in the holder, leaving a small gap between the disc and the holder. This gap does not interfere with the measurements.

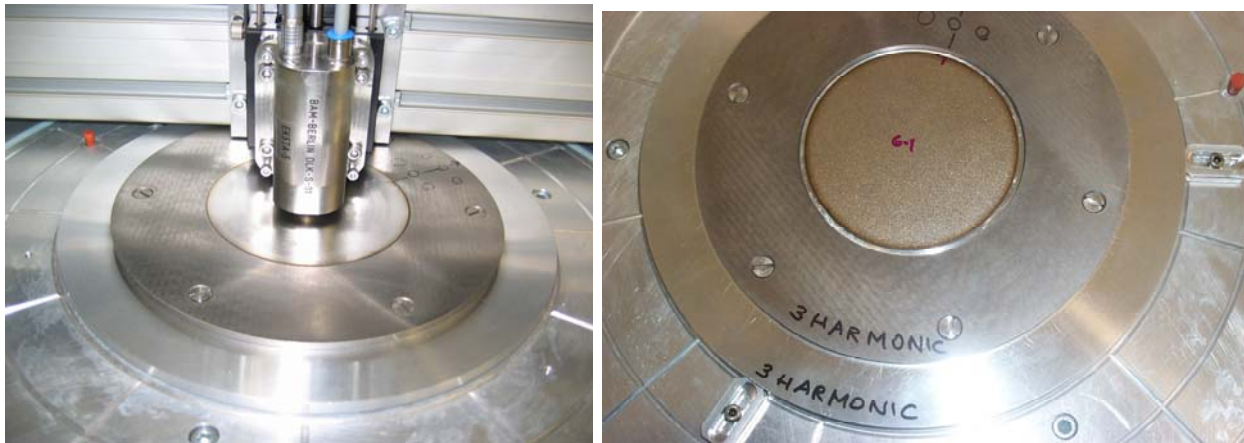


Figure 1: Left: SNS eddy current scanner at Fermilab. Right: gap between sample and sample-holder.

The following procedure was applied to each sample:

Visual Inspection:

¹ P. Bauer et al., "Eddy Current Scanner Operating Instructions", Fermilab Technical Division Internal Note TD-04-029, 08/04

1. The samples were handled using nitrile gloves all the time during visual inspection.
2. The samples were optically inspected, using a magnifying glass when necessary, looking for scratches, pits, dings, discolorations, large surface imperfections.
3. The results were written in the **VISUAL INSPECTION LOG BOOK**.

Scanning:

1. The system was switched on at least one hour before testing. The probe height was adjusted for the first sample to be scanned and kept fixed for all the samples of the batch.
2. Each sample was centered between the holding brackets.
3. The phase was set such as de-couple defects (y-signal) from disc thickness variations (x-signal). The phase adjustment procedure was performed with the probe positioned above the center of each sample.
4. The calibration of the probe signal was automatically performed on the mid-radius of each disk.
5. Each side of the samples was marked at the top-right corner in correspondence of the 0 angle of the scanner rotating plate with a 1 for the first side scanned and a 2 for the second side scanned
6. The scanning information were reported in the **ECS LOG BOOK**
7. The scan results were saved in NSD, NSX and BMP formats using the following convention: **3harm_b1_disc#_disc-side_run#** where discs were sequentially assigned a disc number from 263 to 204.
8. The scan results were filtered using FIONDA and a image of the results was saved in JPG format using the same naming convention as in point 7
9. Printouts of the BMP and JPG files were archived in a folder (Q:/TD_SCRF/SRFMaterialsLab/ECS/3harm)

Post Processing:

1. The visual inspection and the scanning results were compared
2. Samples needing additional measurements were selected: anodization, etching, degreasing, microscopy, ultrasound thickness measurements and profile measurements where used as additional diagnostic techniques. The results of these measurements are reported at the end of this report.

Figure 2 shows several scans of the calibration disc (b1-22/2) obtained before and after the scanning campaign reported here. Also shown is a scan of a similar disc performed by DESY.

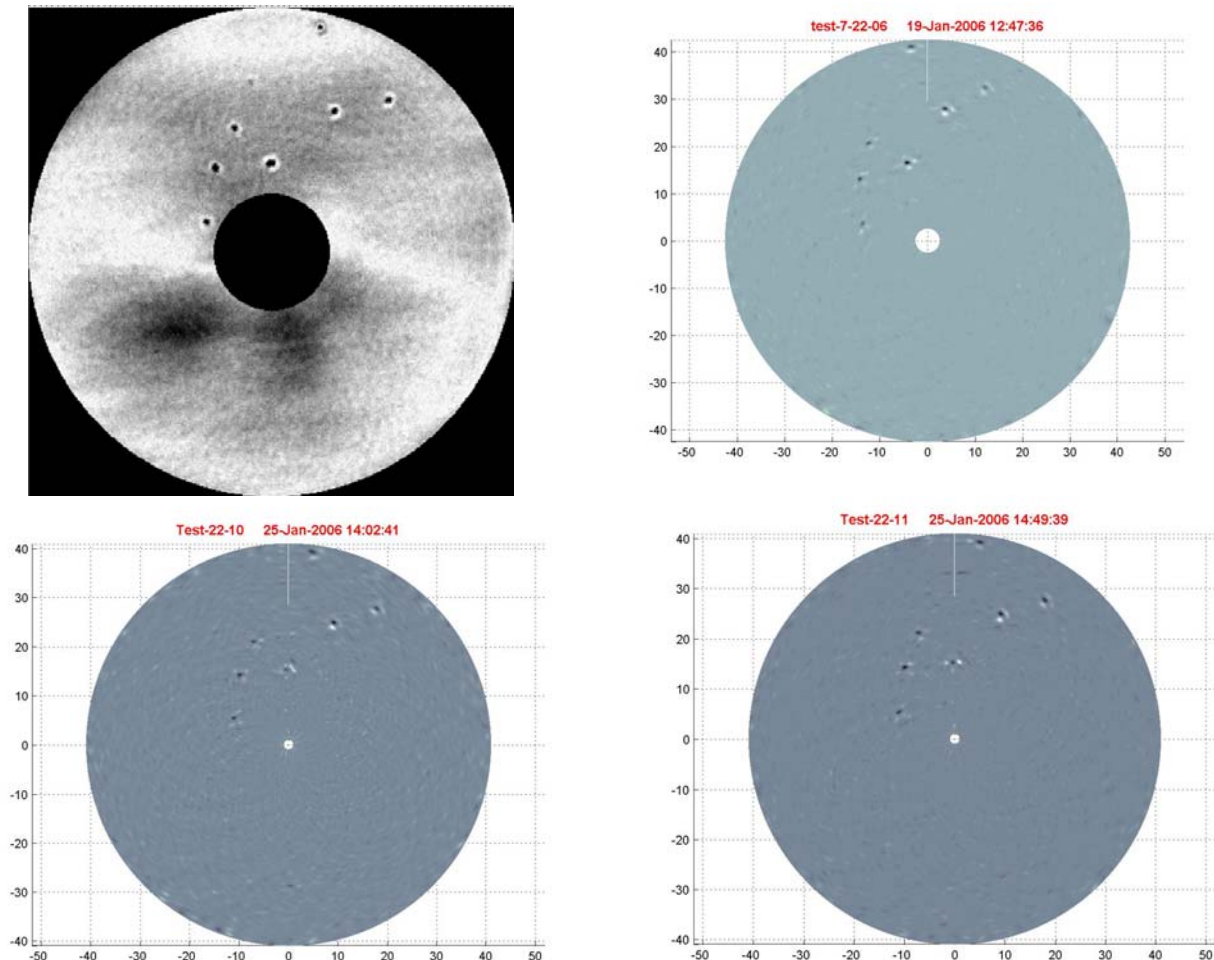


Figure 2: Example of eddy current scans performed on a niobium disc for Fermilab's 3rd harmonic cavity with the DESY scanner (top left) and SNS/FNAL scanner (top right and left & right bottom). The bottom two scans were obtained after the measurement campaign reported here, the one on top right, before. **GET disc 22 SCANS FROM MARCO!!!!!!!**

The typical scanner settings for the scans are summarized in **Error! Reference source not found..** The data shown in the following chapters are all of channel 1 (y-signal). The results obtained with the high frequency (1.2 MHz) channel (2) are not understood to this date and the results are therefore not discussed further here.

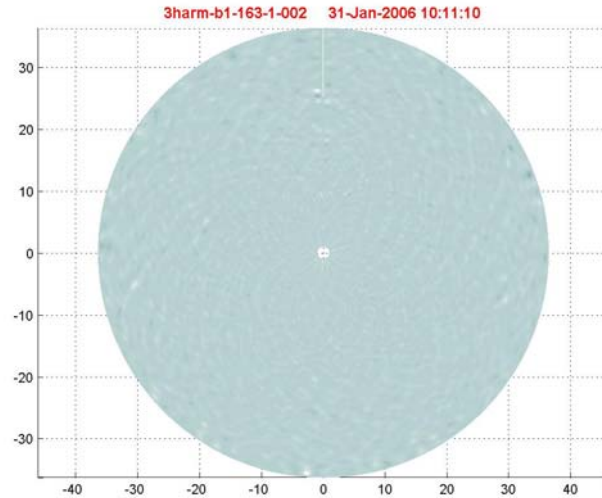
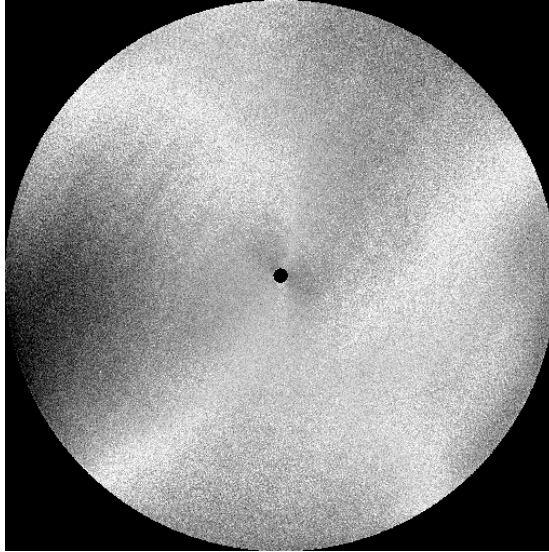
The table below lists the operational parameters of the eddy current scanner.

Parameter	Channel 1 – SNS/FNAL
Frequency	190 kHz
Probe Adjust	50 Ohm
Probe Current	333 mA
Phase	205 deg
Pre-amplifier	30 dB
Total gain (x/y)	46/66dB
X/Y spread	0/20 dB
Highpass filter	static
Lowpass filter	0.5-2 kHz
BW limit	off
Track spacing	50 μ m ?????
Point spacing	0.225°
Turntable speed	105 rpm

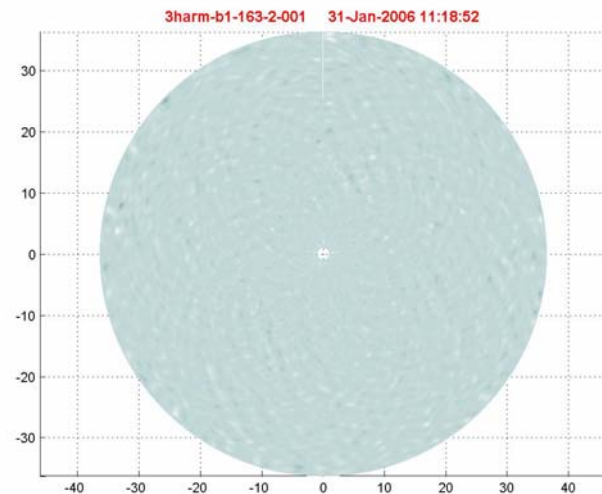
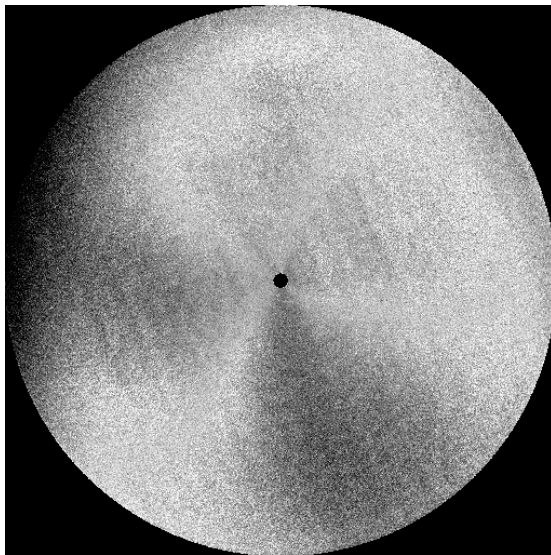
Table 1 Scanning parameters

2 SCANNING RESULTS

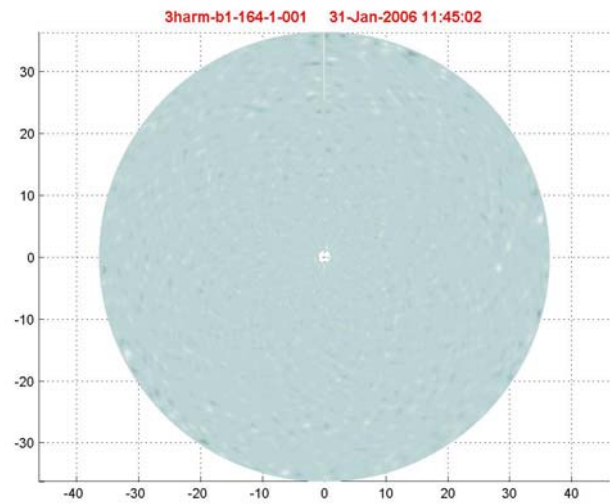
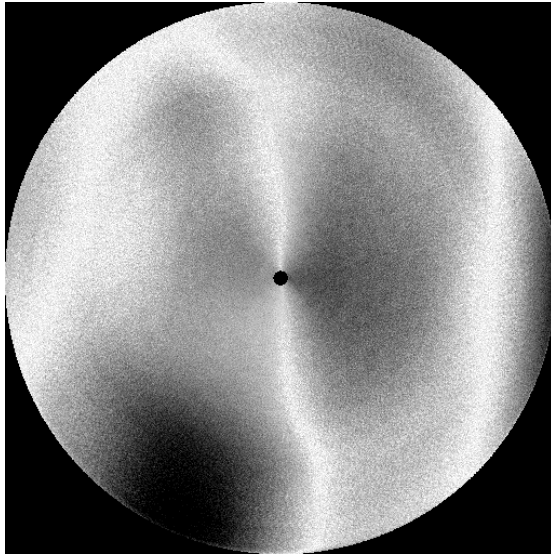
The following shows the scans obtained on discs 163-204. In some instances multiple scans needed to be performed to achieve satisfactory results. For each side of the disks two pictures are available: one as computed by NiobScan and one resulting from the filtering process using Fionda. Typically the end-point of the EDM-cut is chosen as the reference position (12:00).



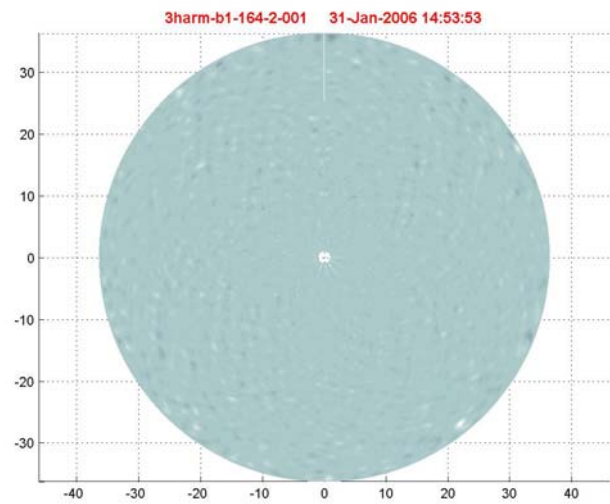
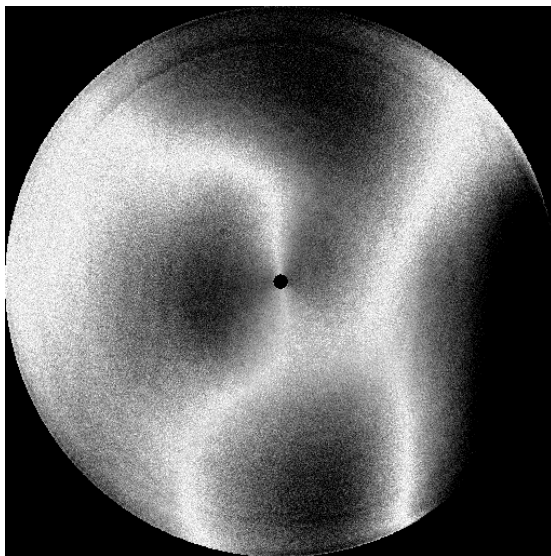
Disk 163 side 1 scan left, Filter right



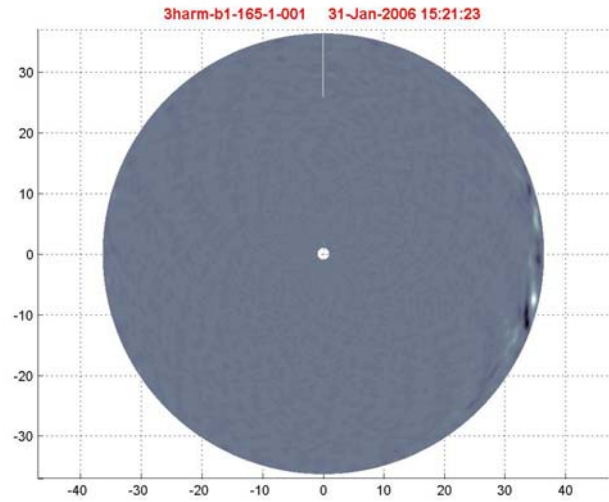
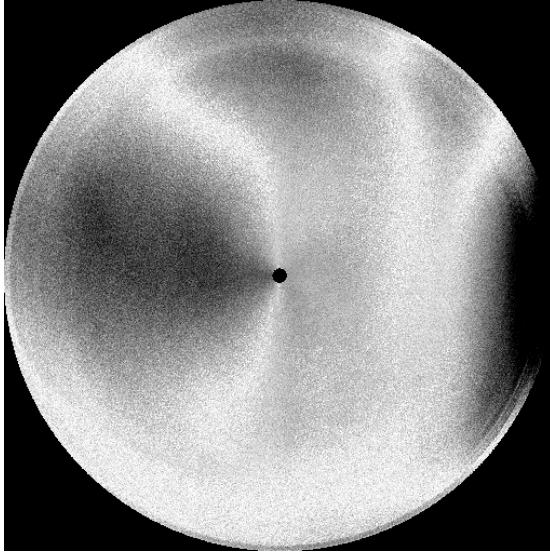
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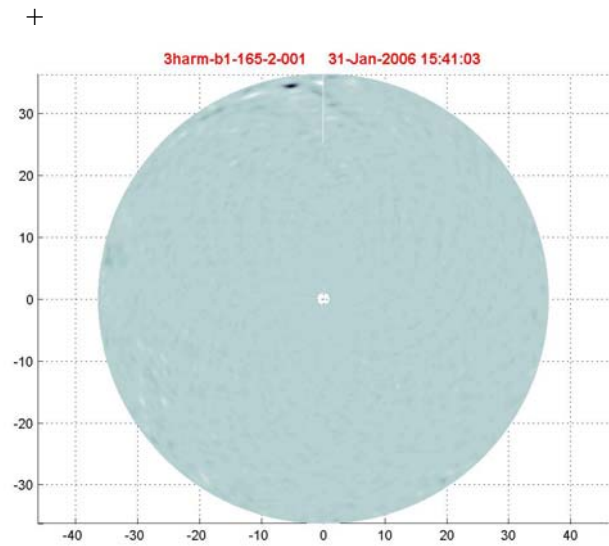
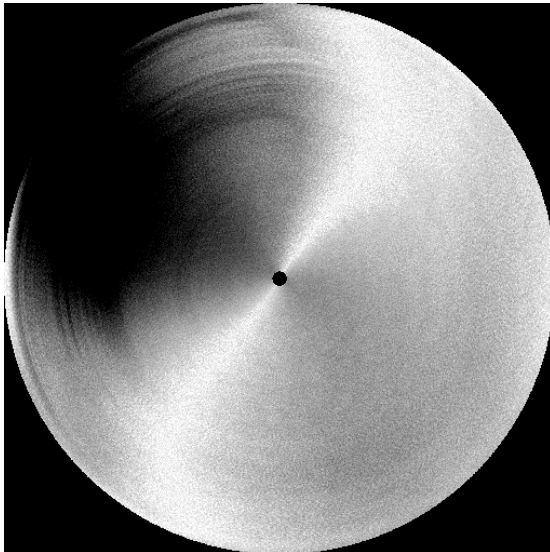
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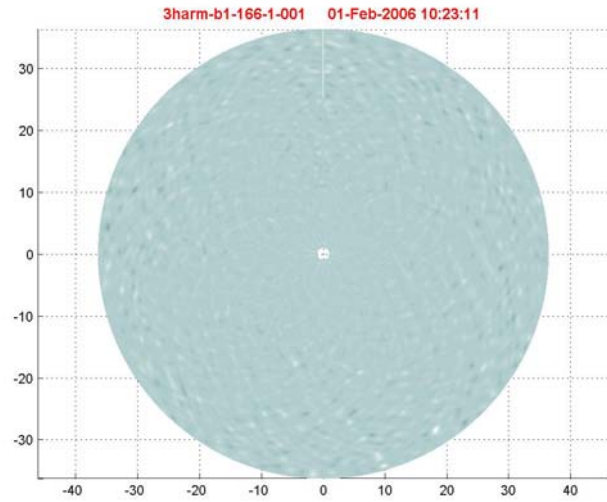
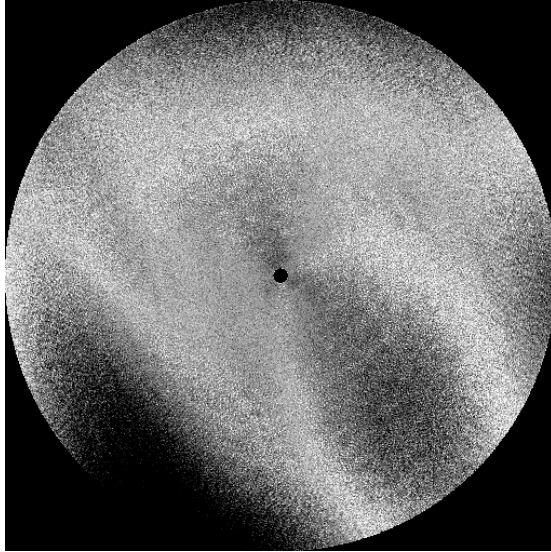
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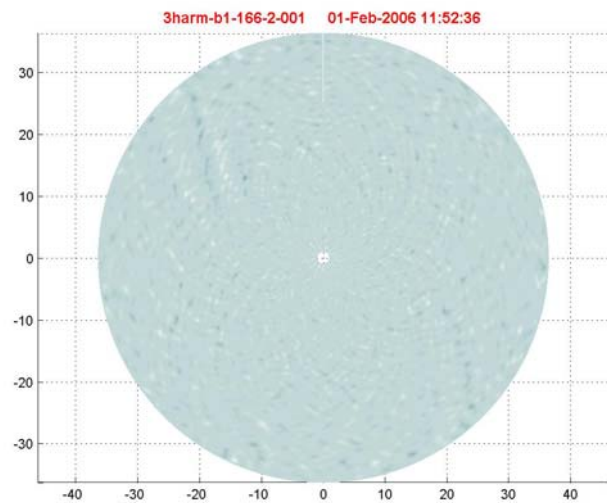
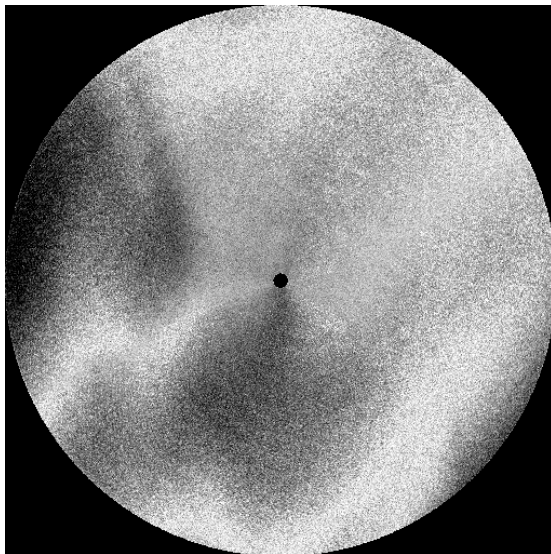
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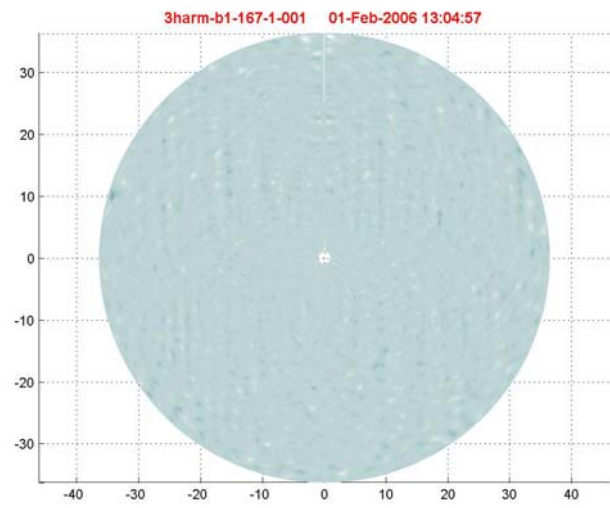
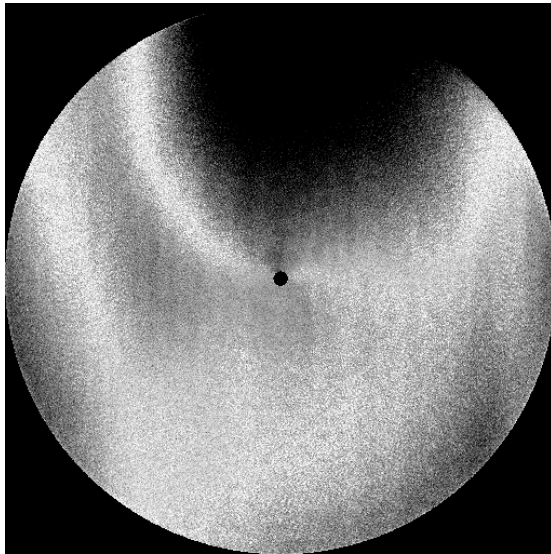
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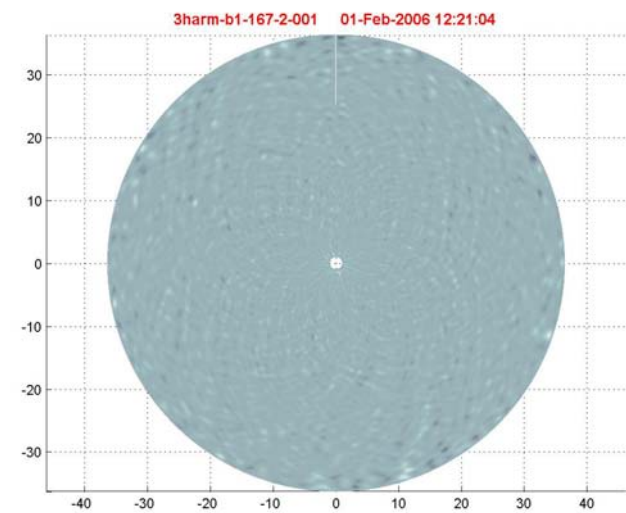
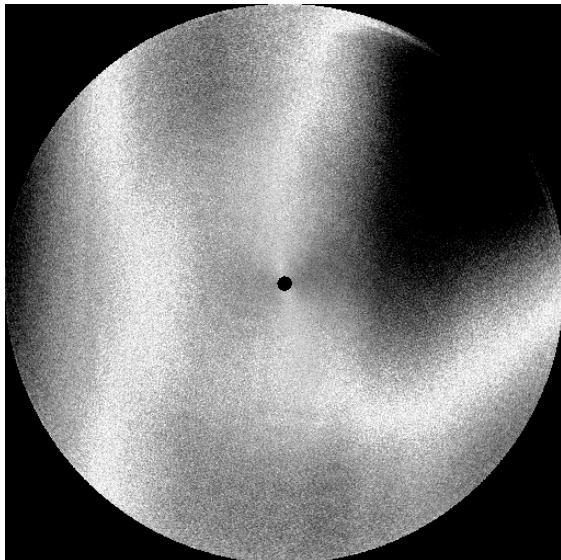
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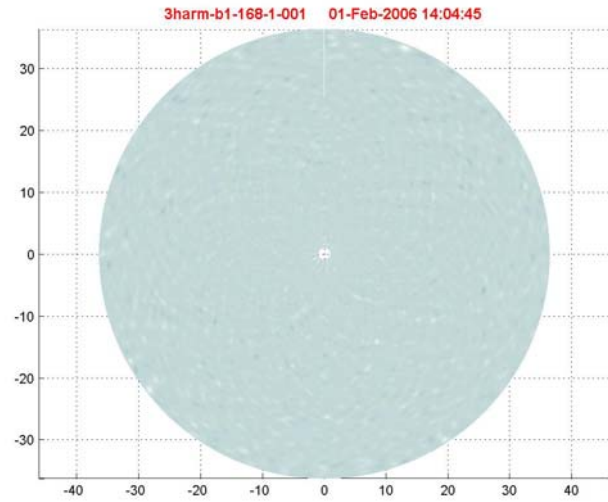
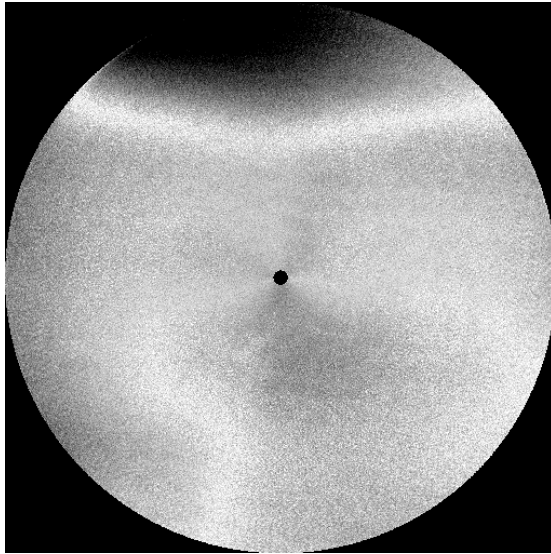
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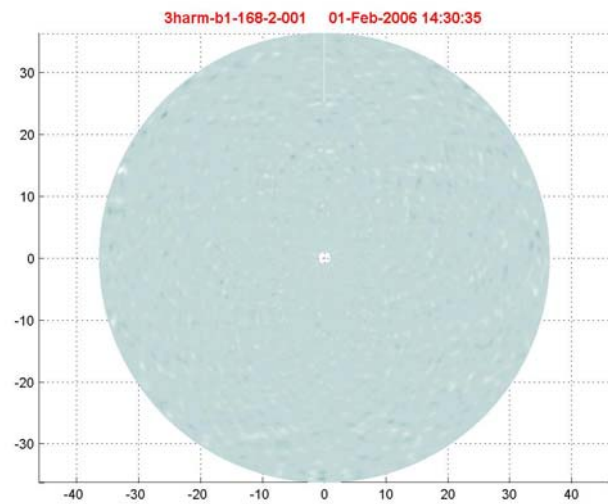
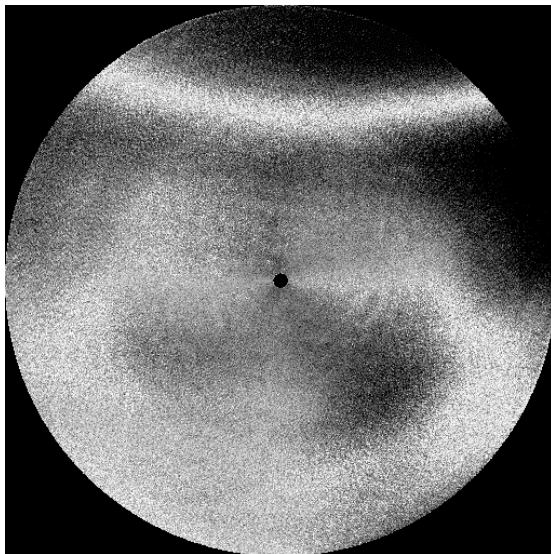
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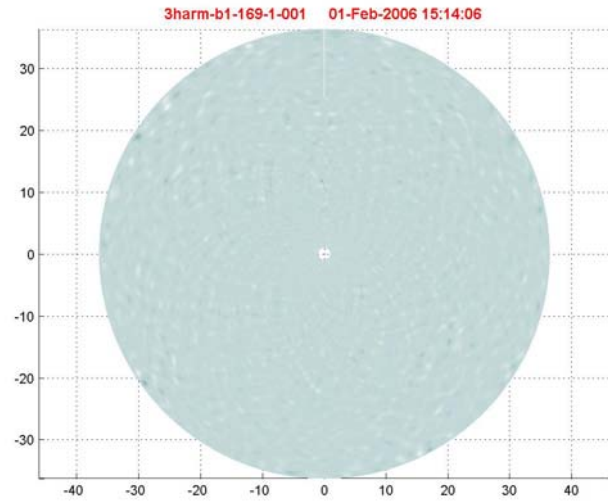
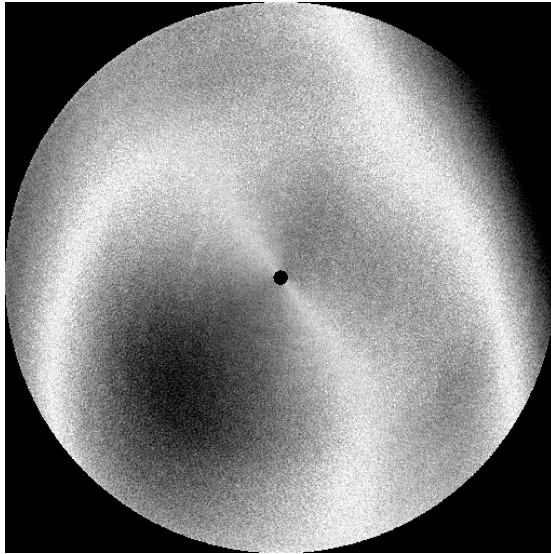
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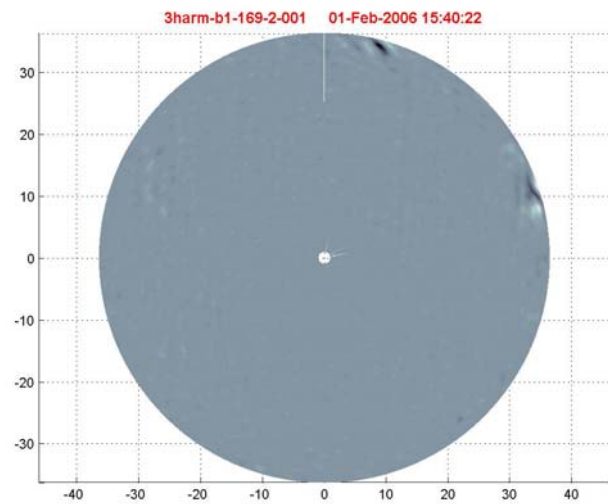
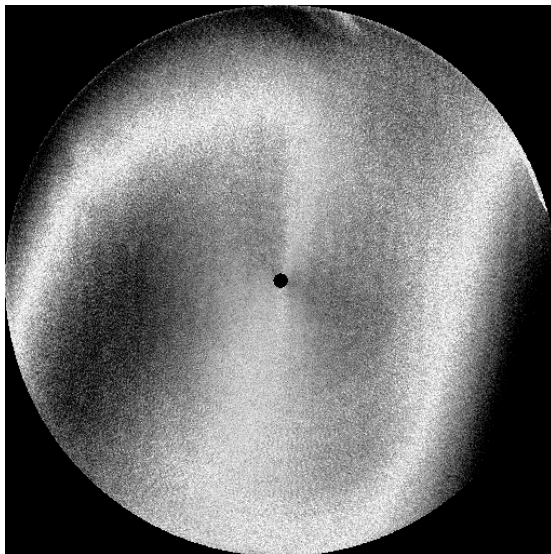
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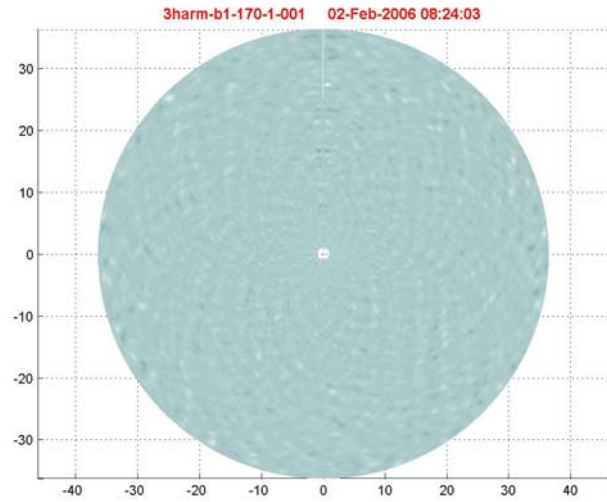
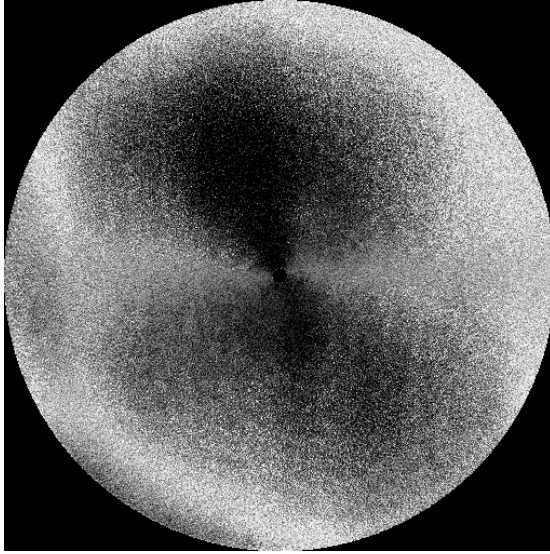
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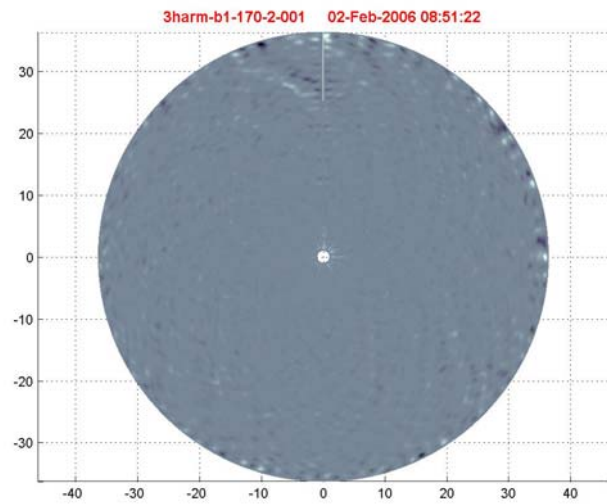
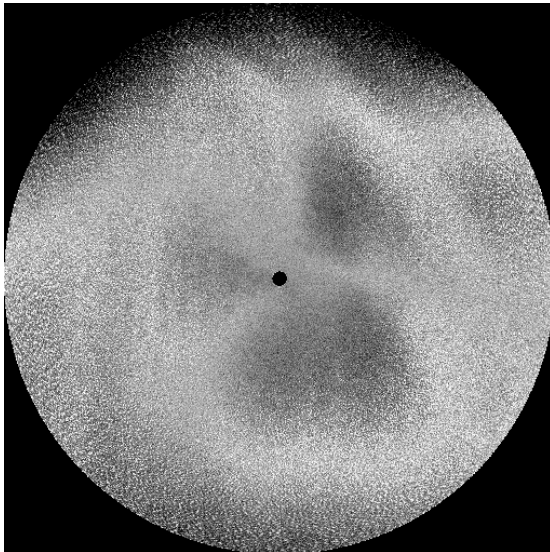
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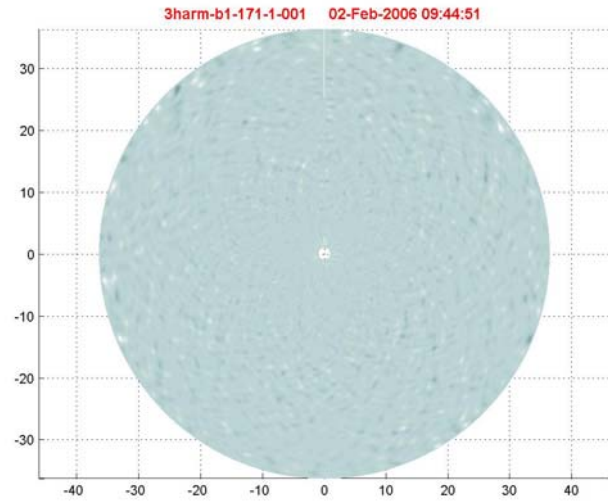
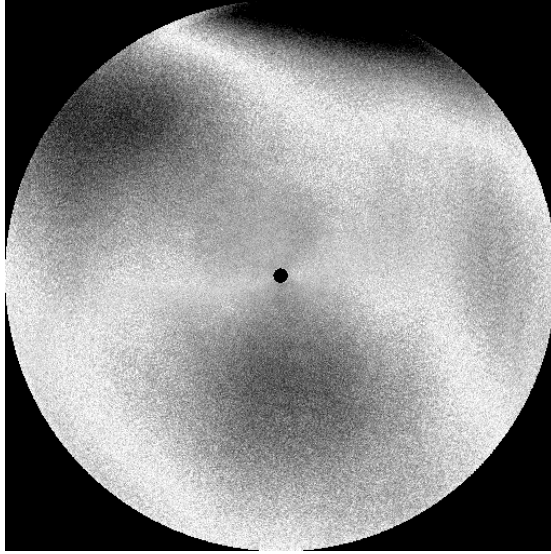
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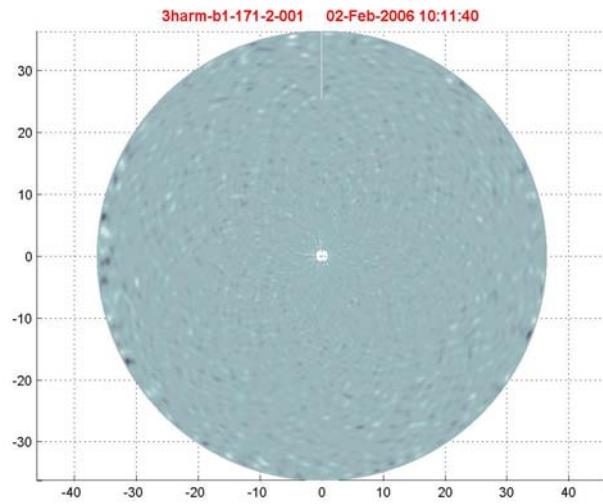
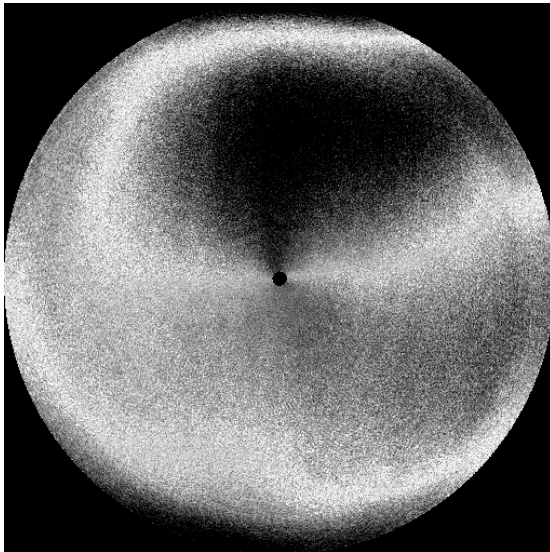
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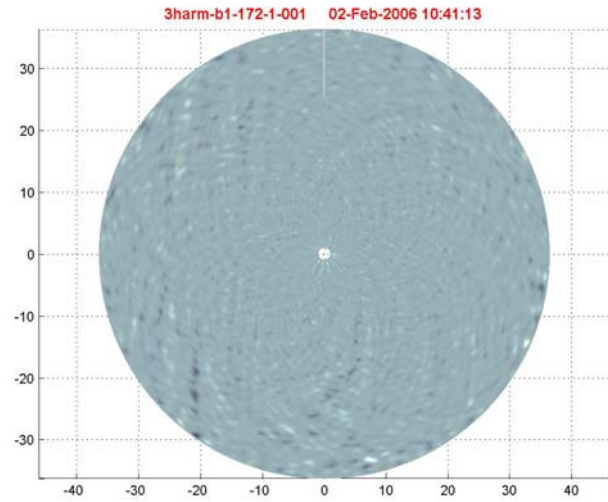
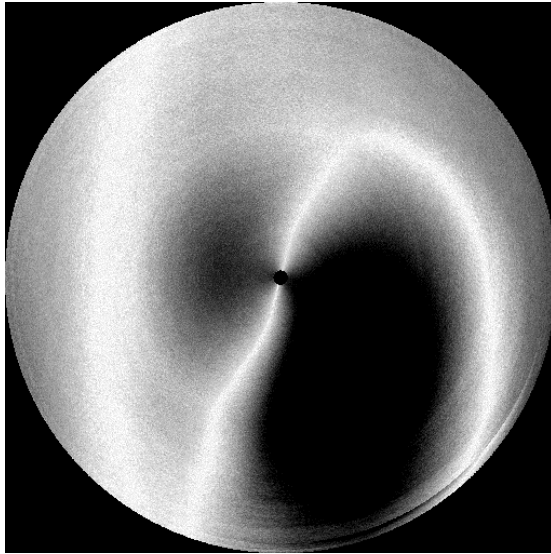
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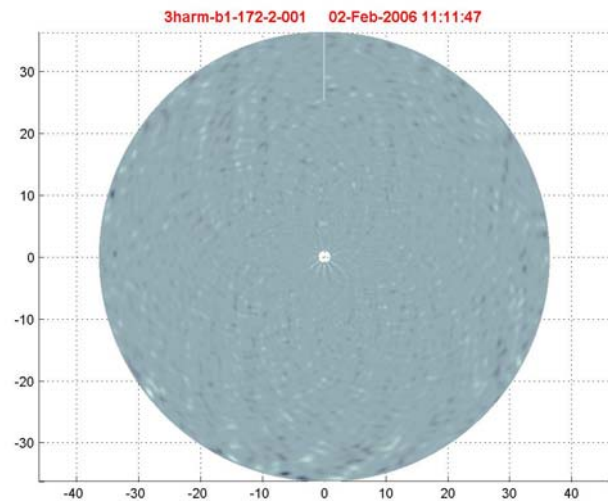
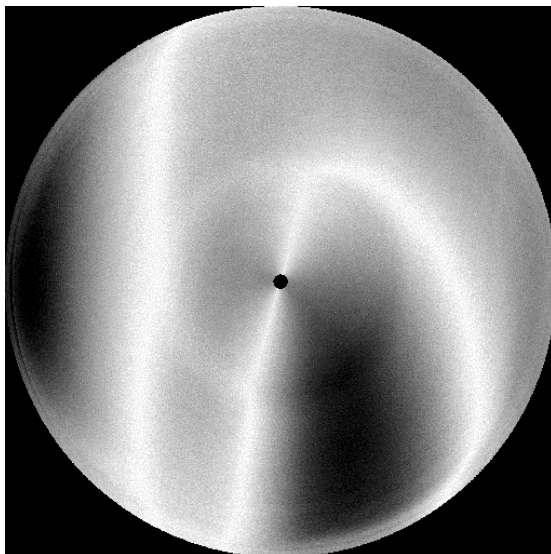
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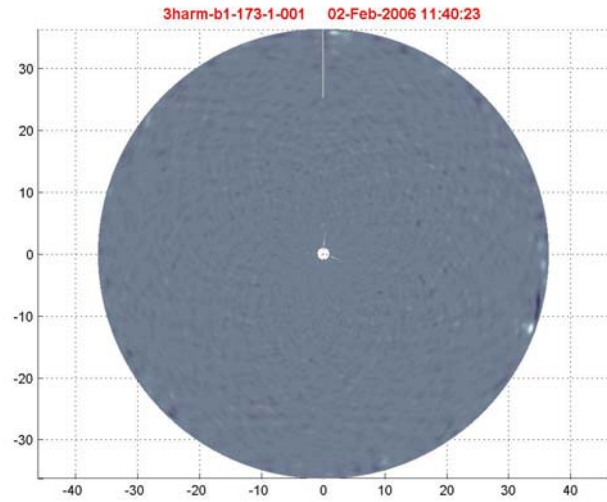
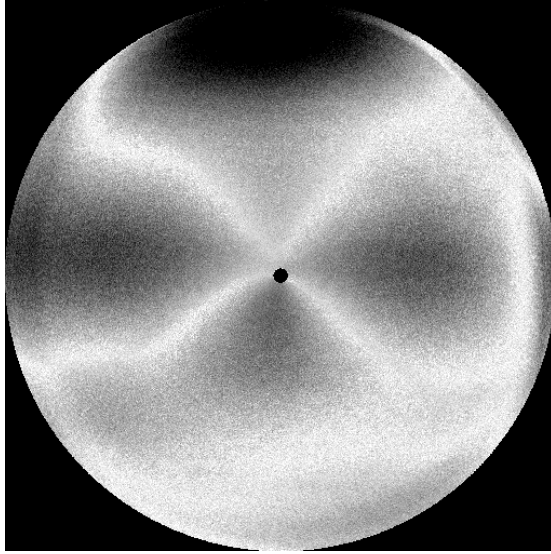
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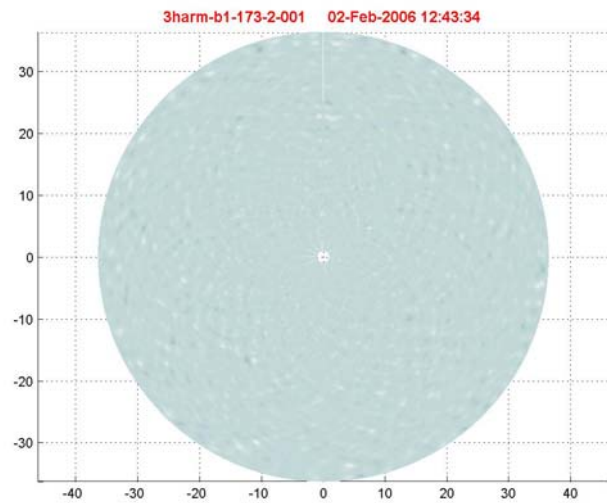
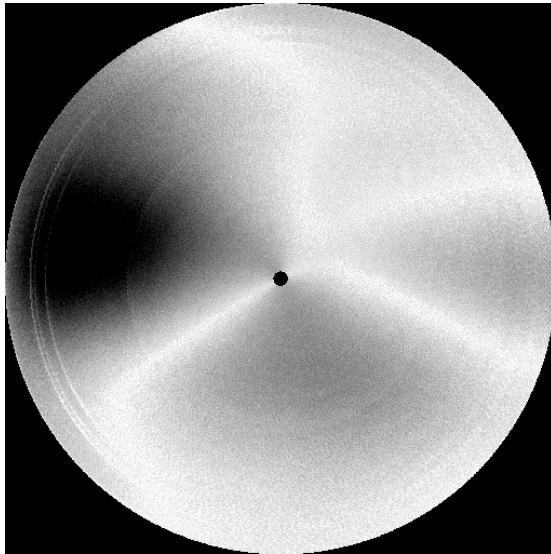
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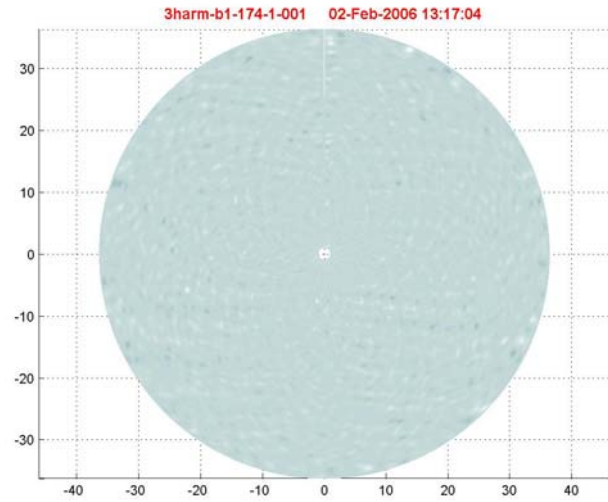
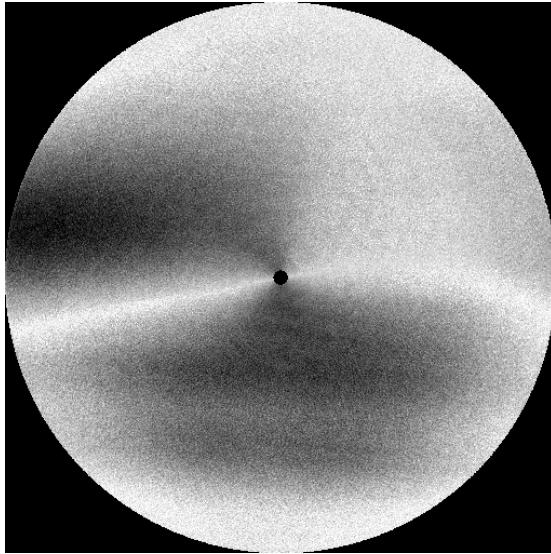
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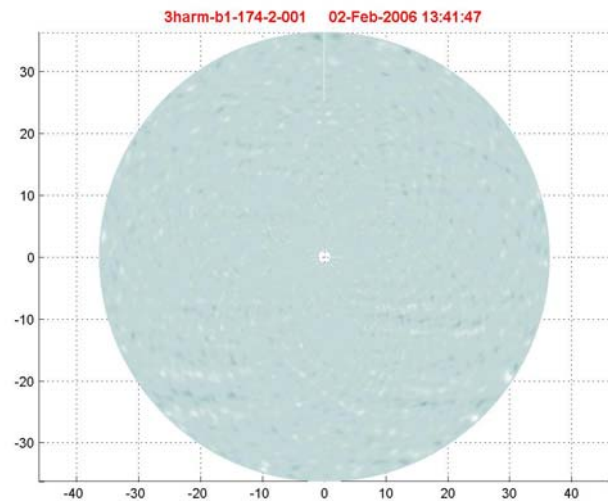
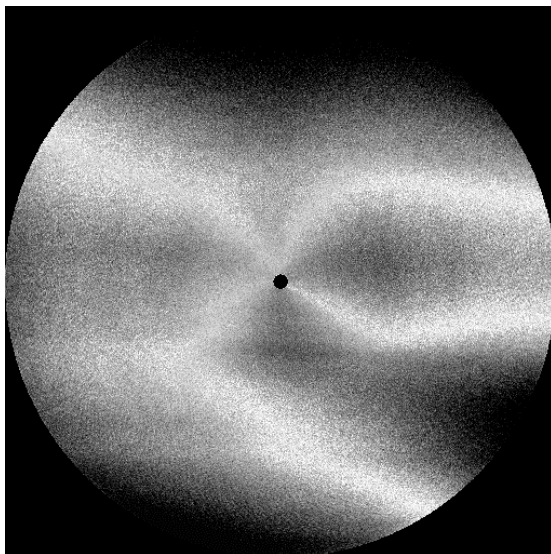
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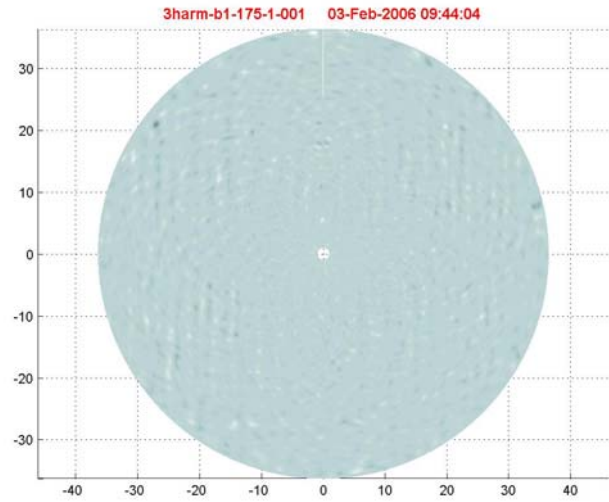
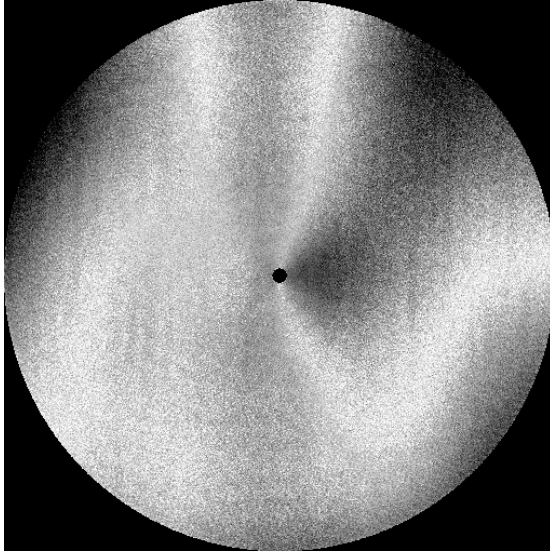
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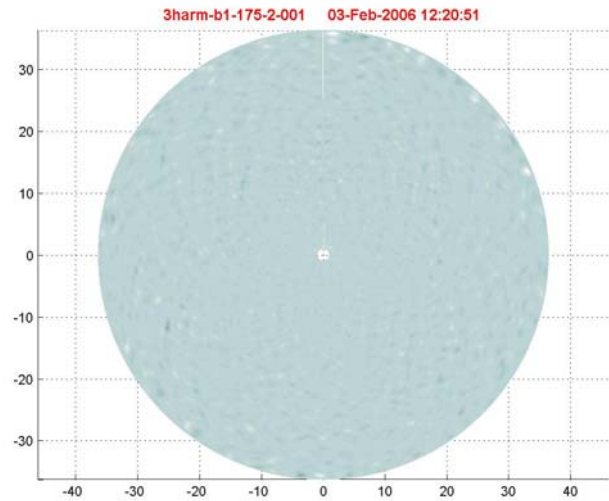
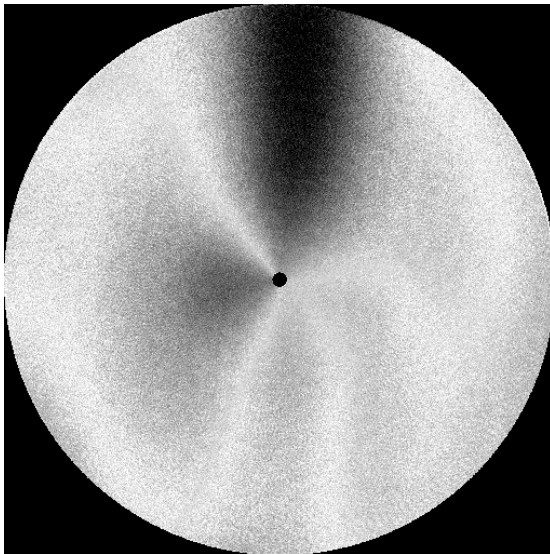
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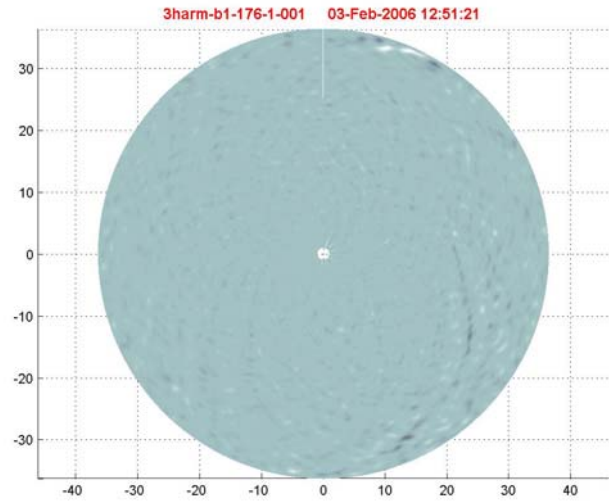
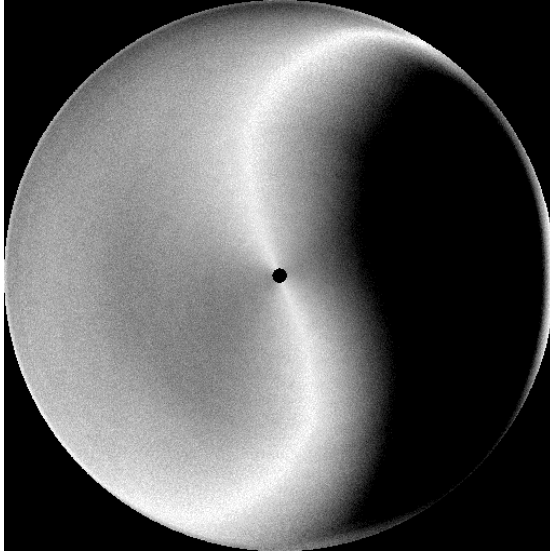
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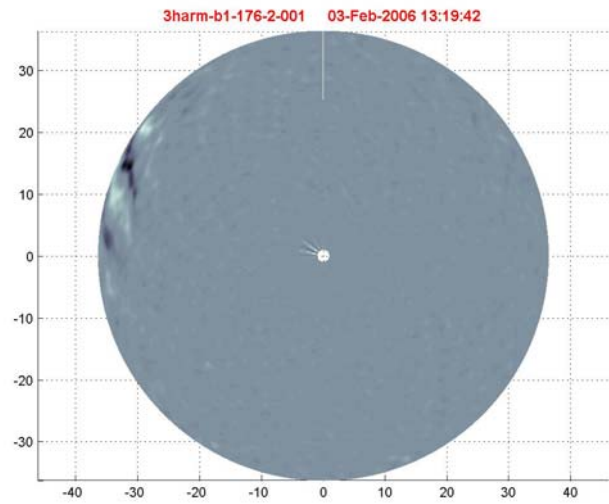
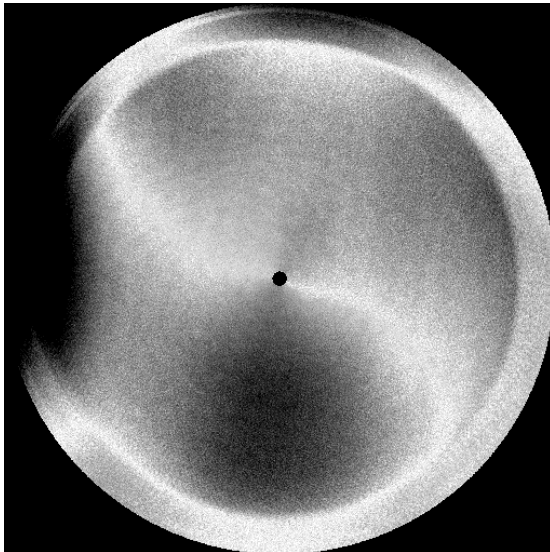
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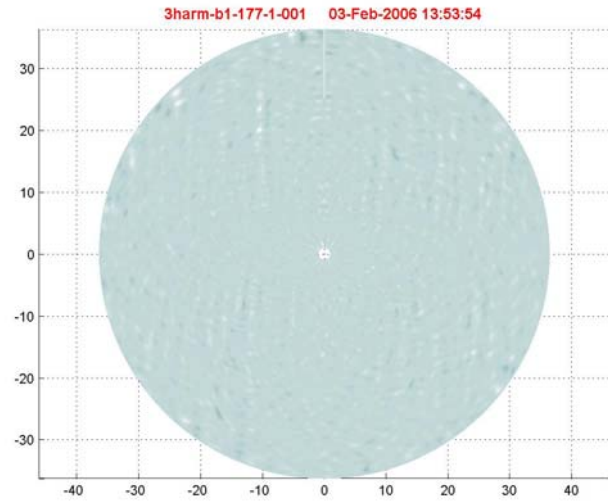
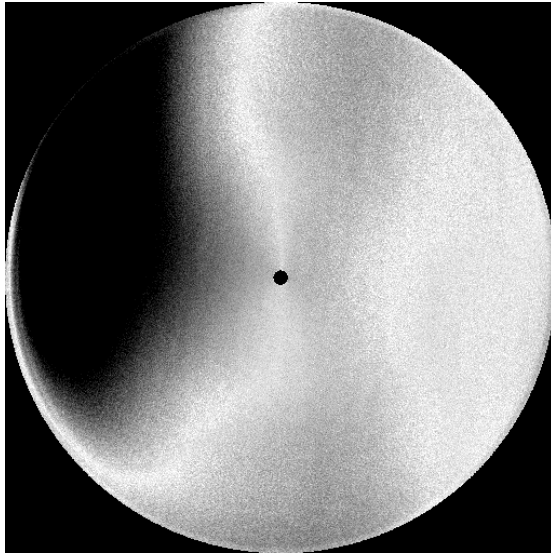
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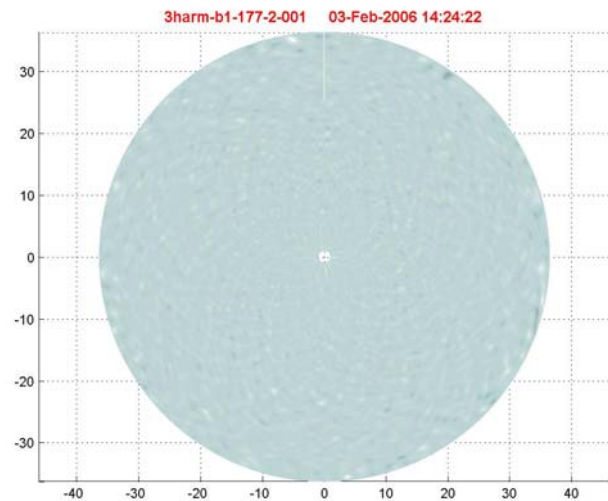
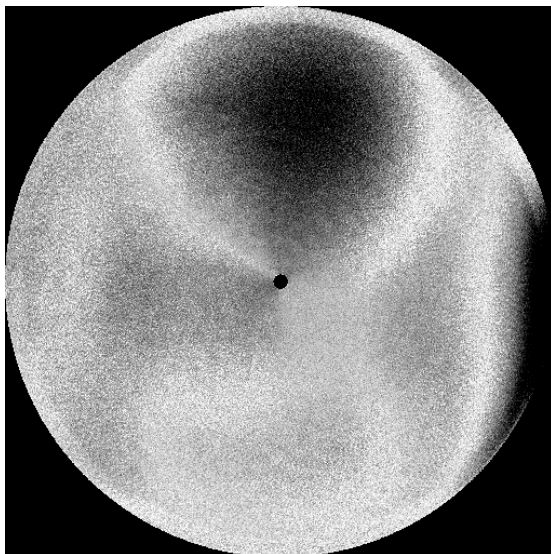
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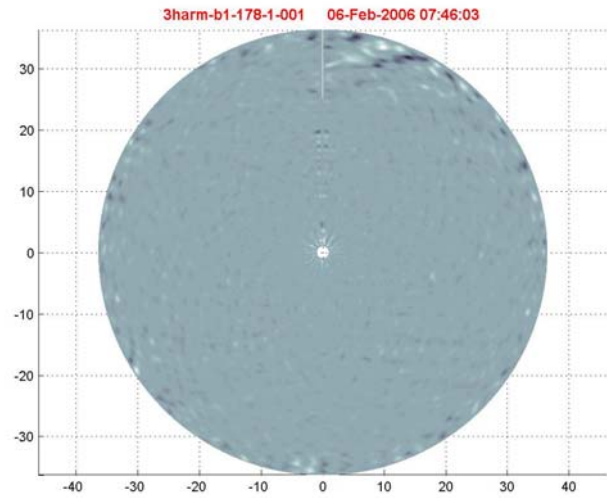
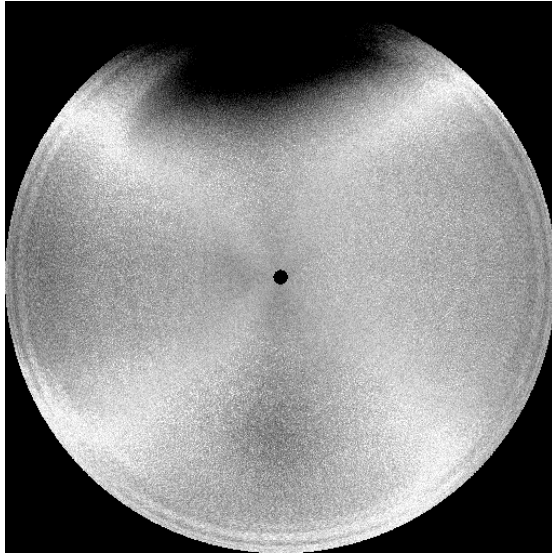
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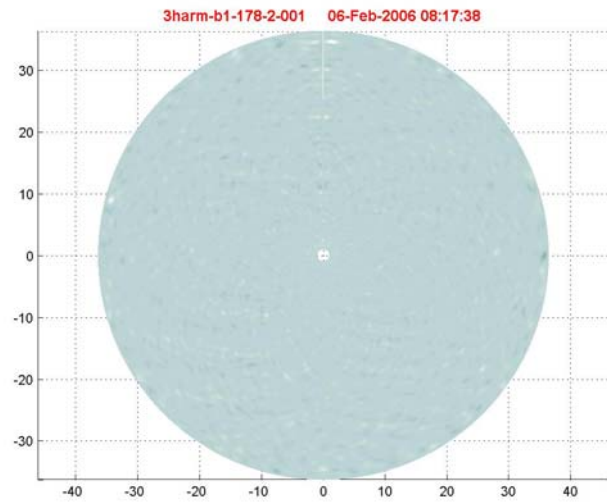
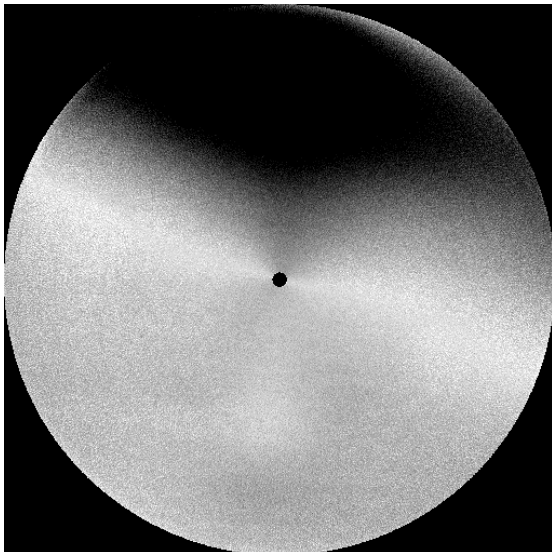
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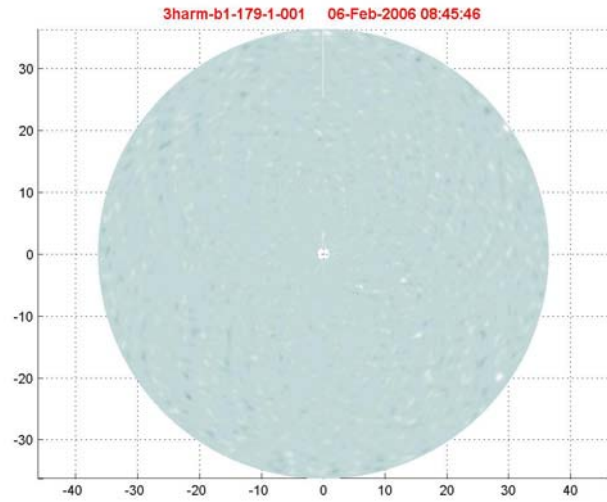
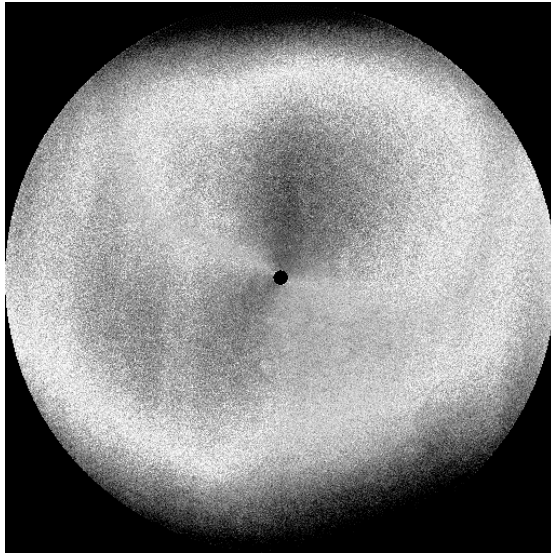
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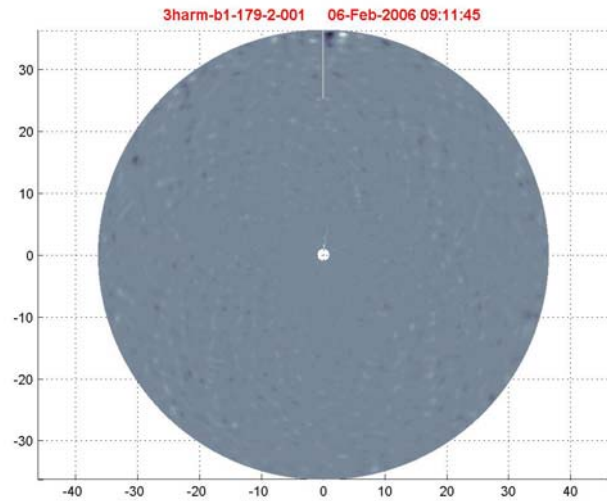
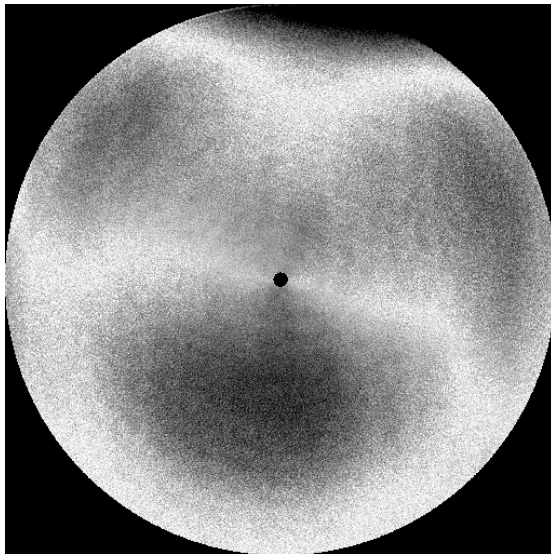
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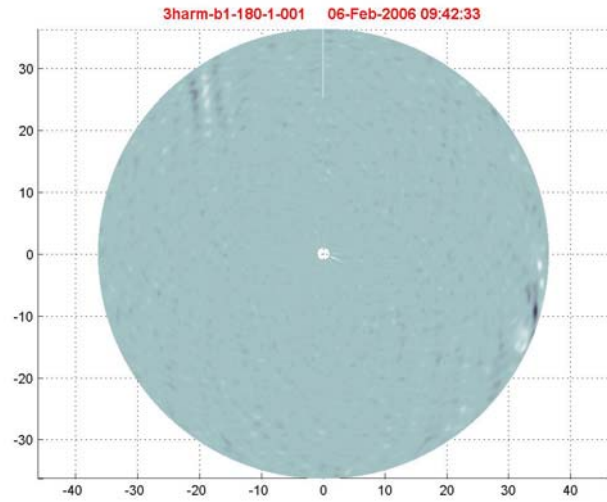
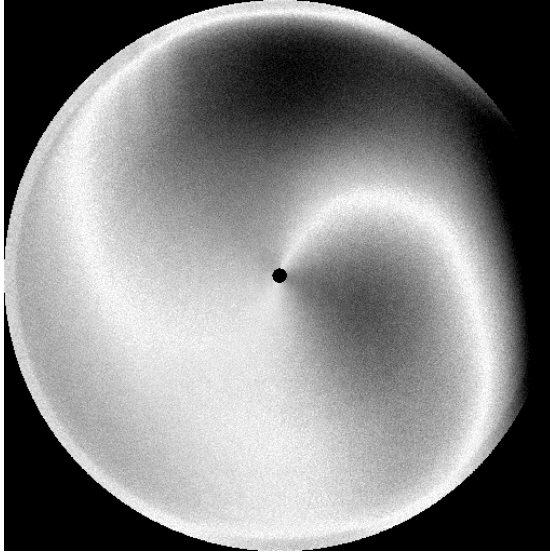
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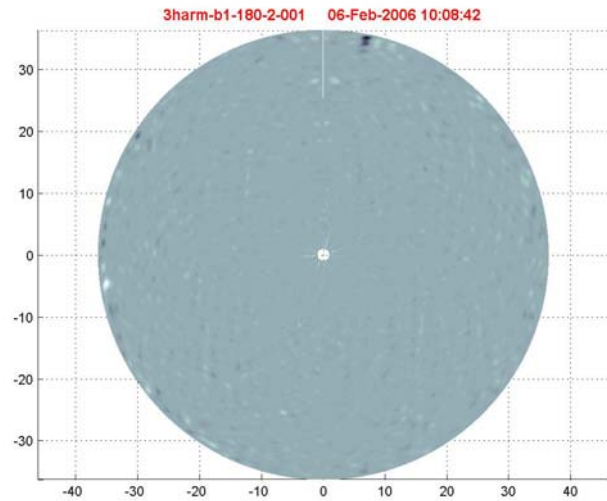
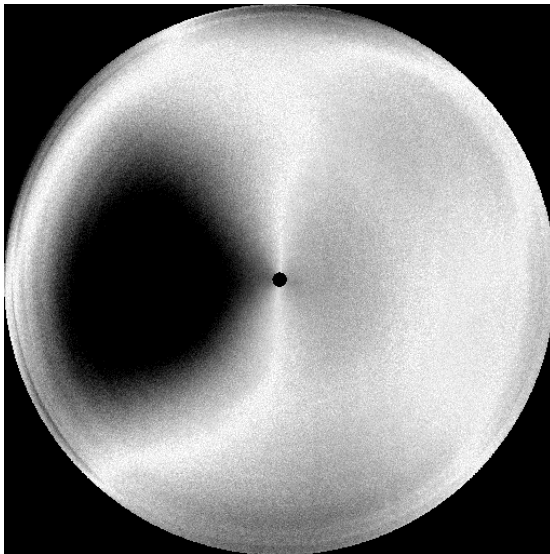
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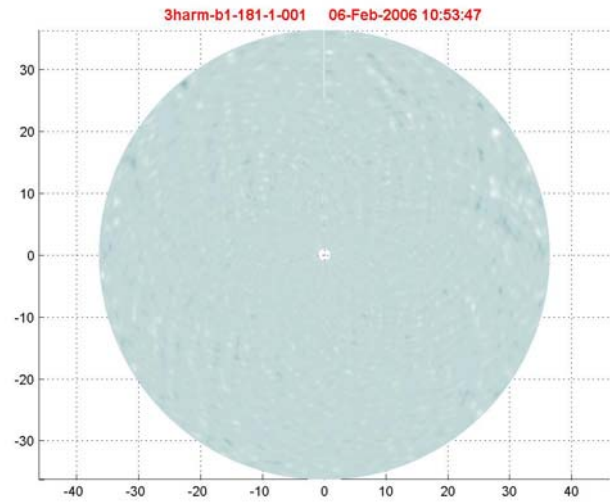
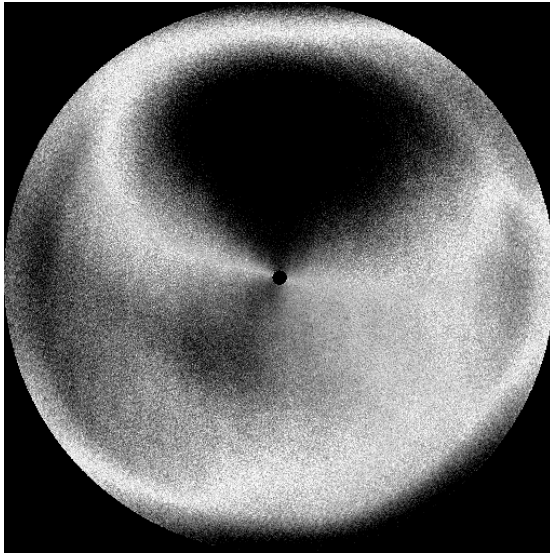
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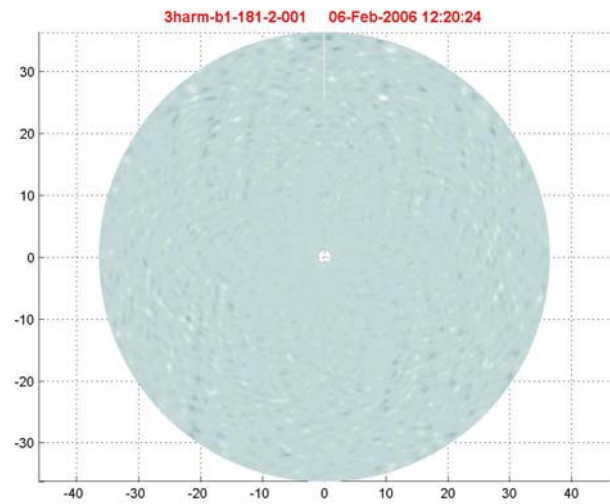
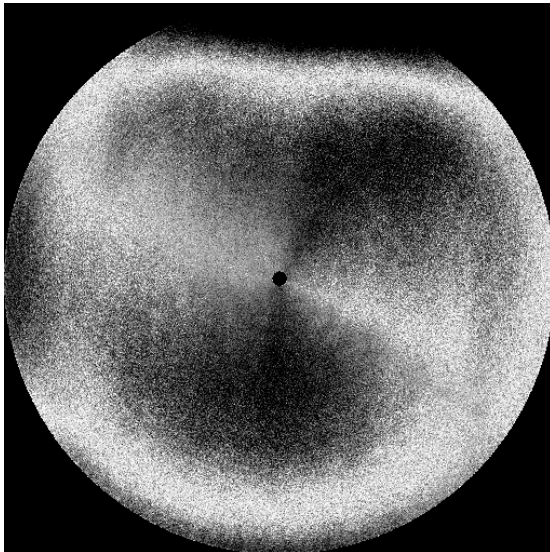
Disk 180 side 1 scan left, Filter right



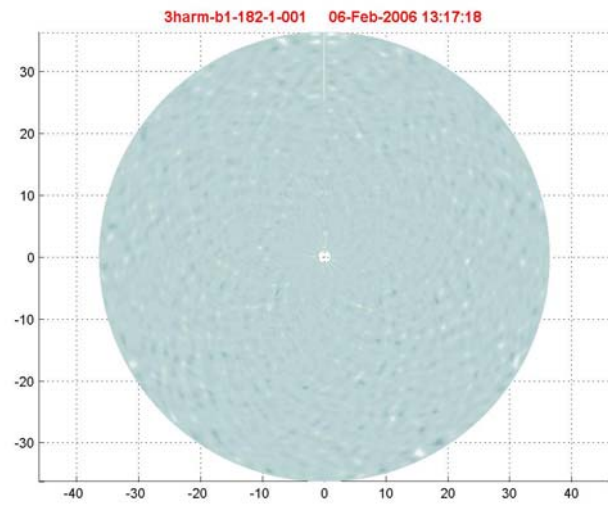
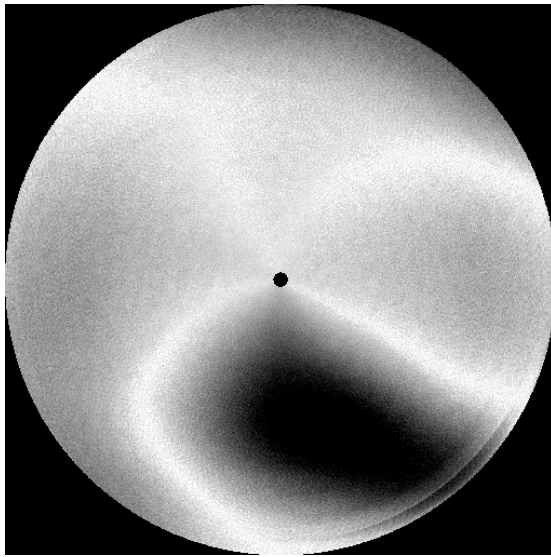
Disk 180 side 2 scan left, Filter right



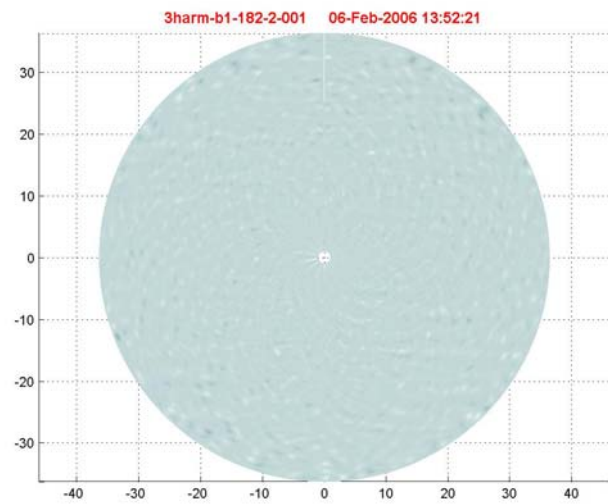
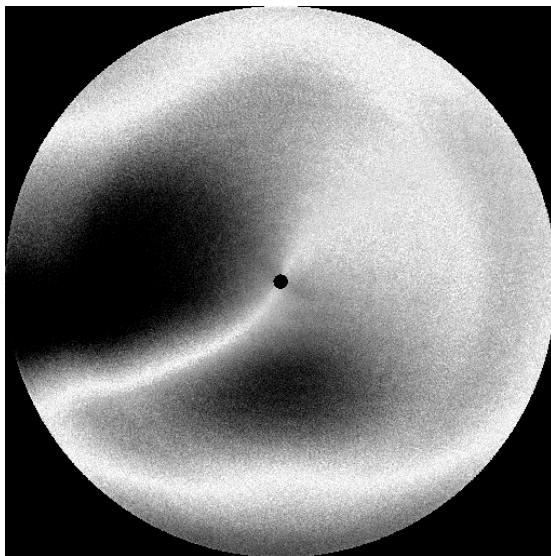
Disk 181 side 1 scan left, Filter right



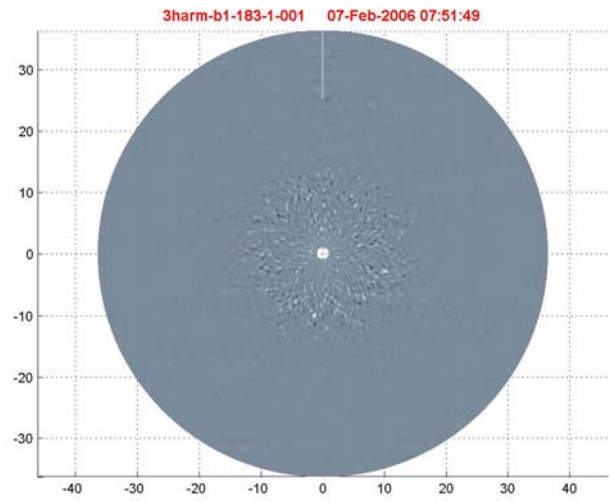
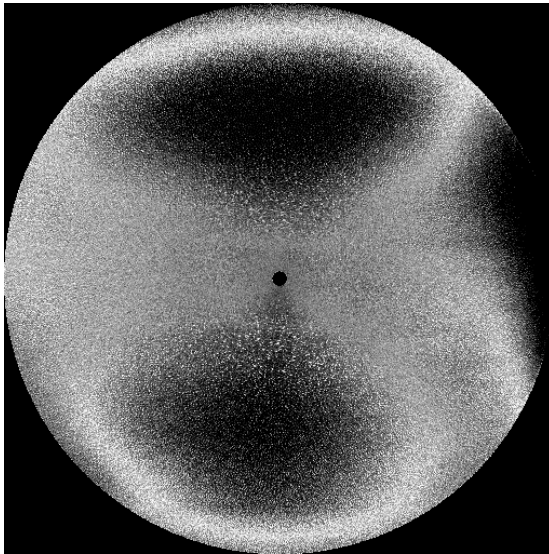
Disk 181 side 2 scan left, Filter right



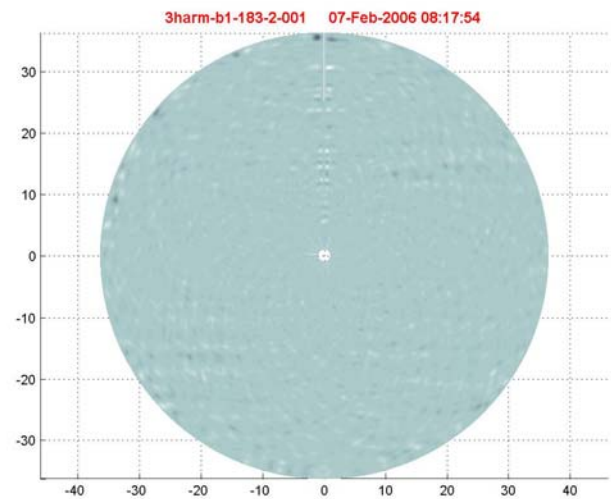
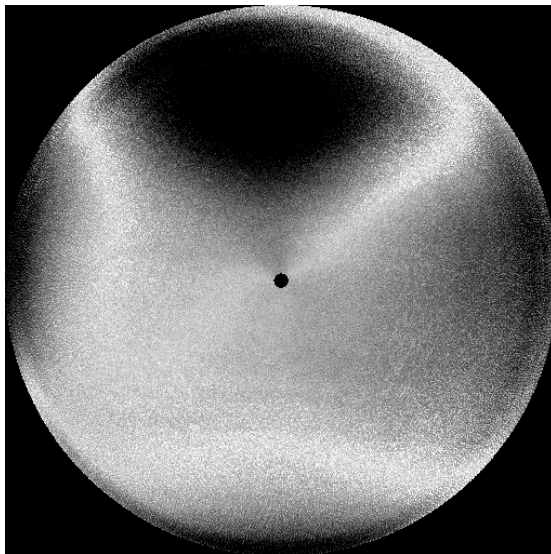
Disk 182 side 1 scan left, Filter right



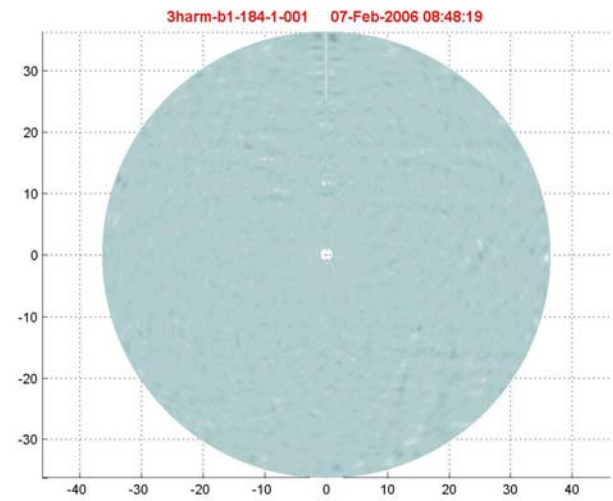
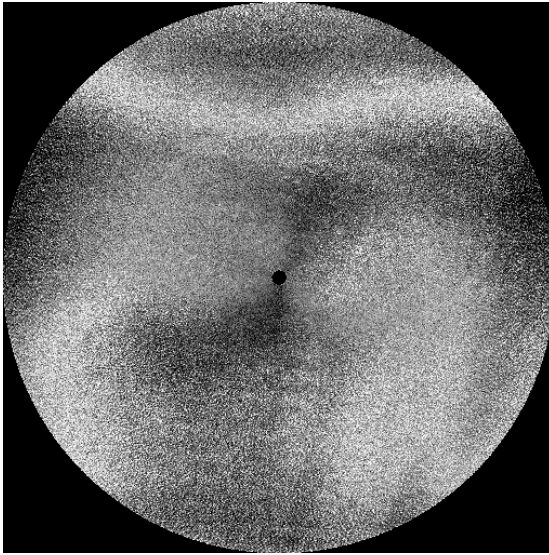
Disk 182 side 2 scan left, Filter right



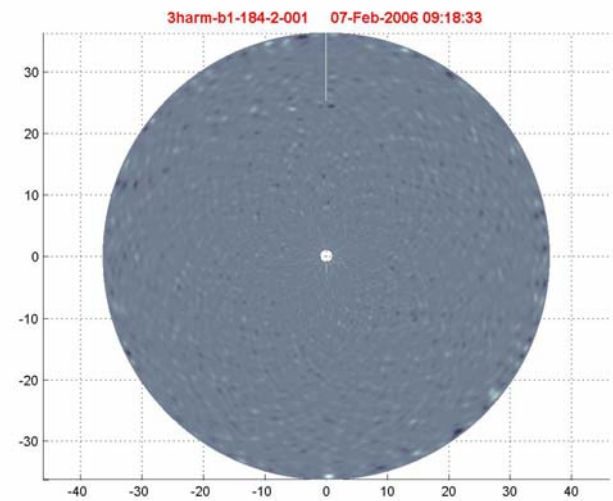
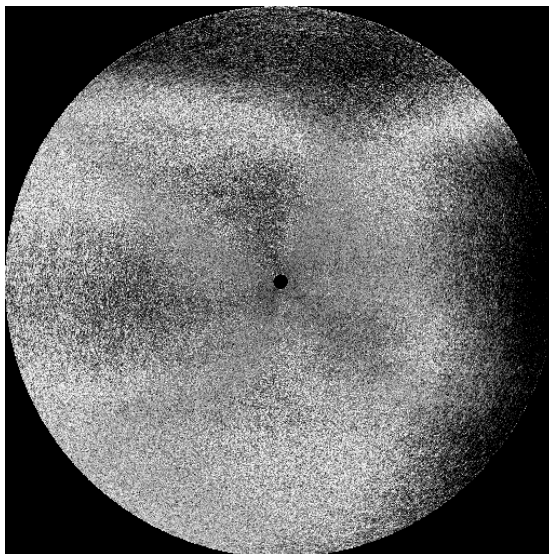
Disk 183 side1 scan left, Filter right



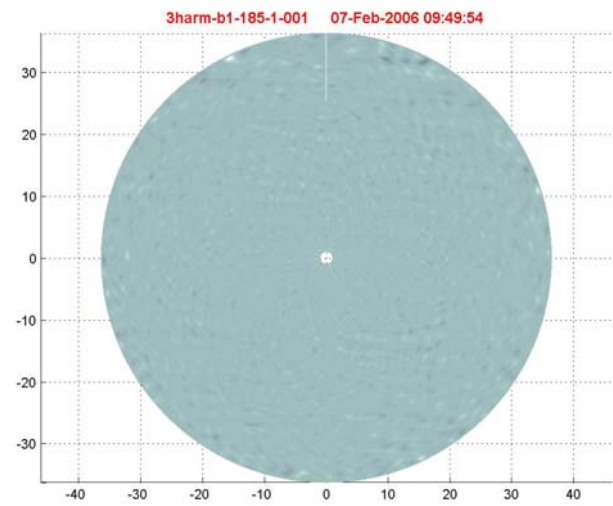
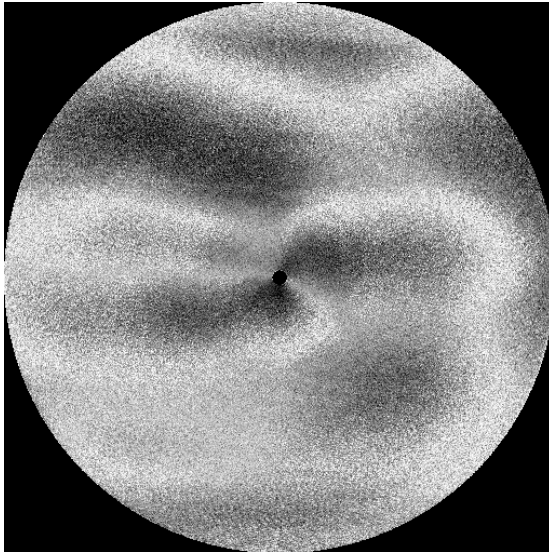
Disk 183 side 2 scan left, Filter right



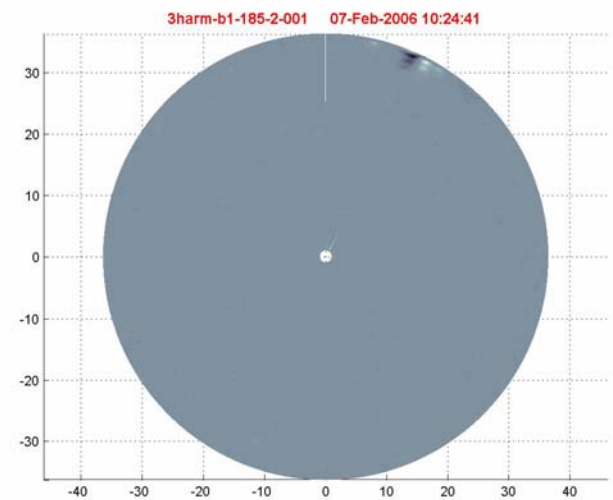
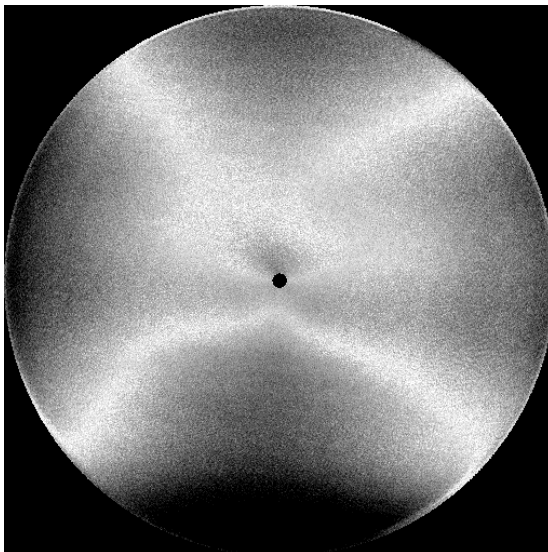
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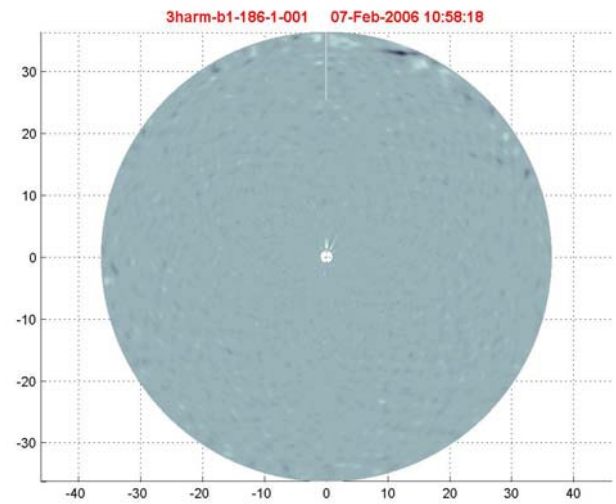
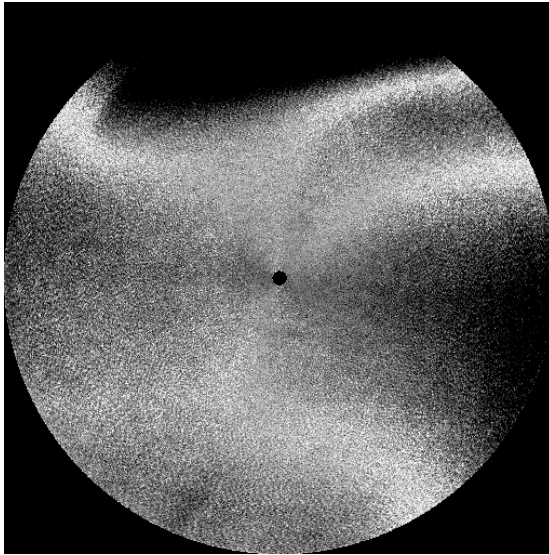
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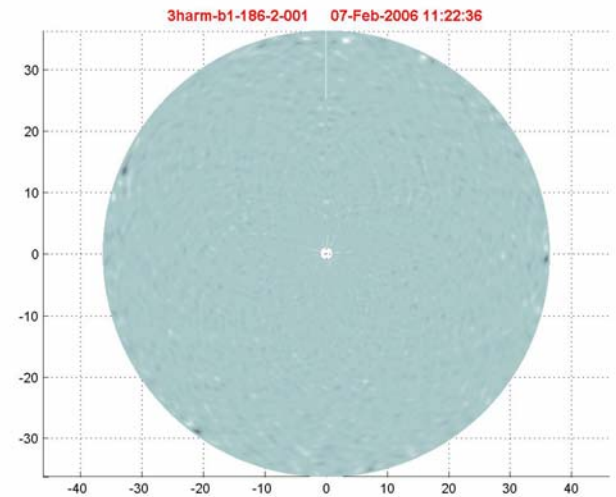
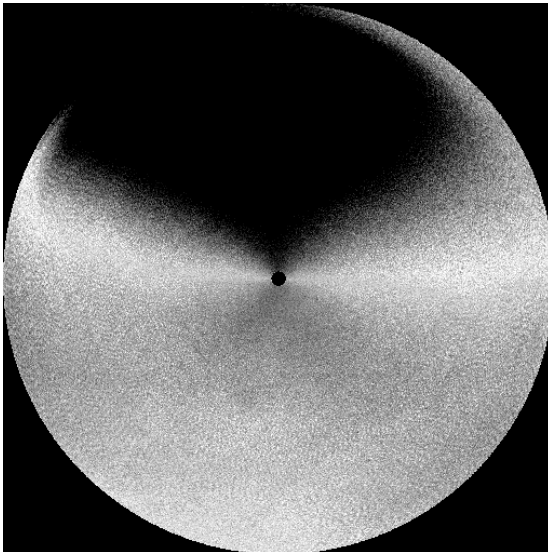
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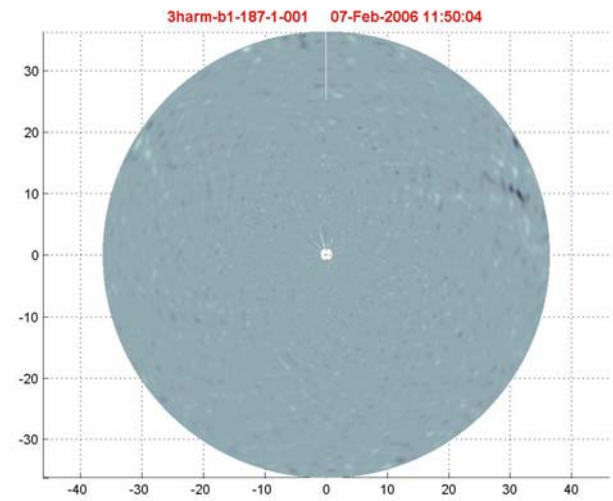
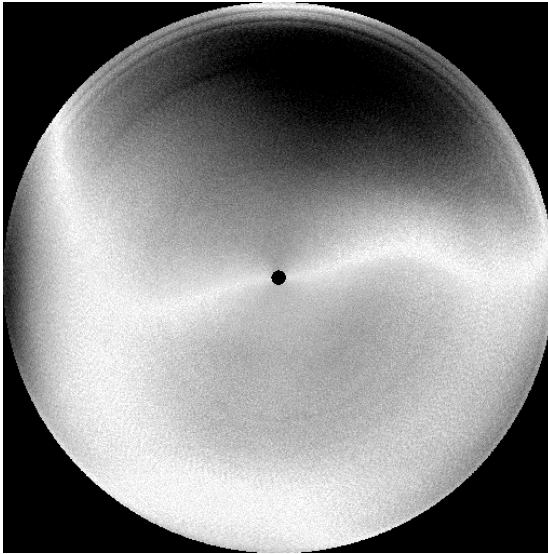
Disk 185 side 2 scan left, Filter right



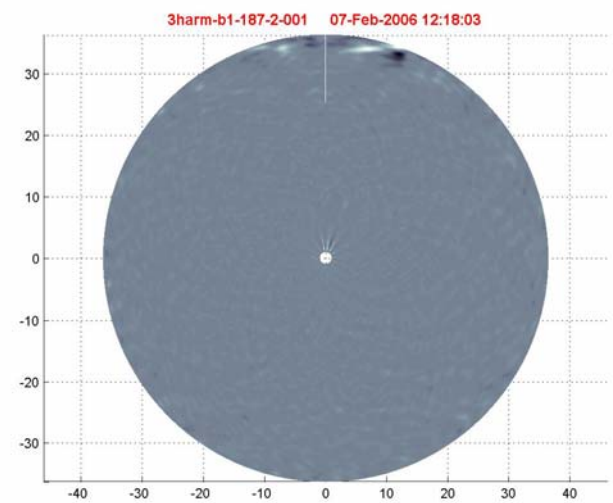
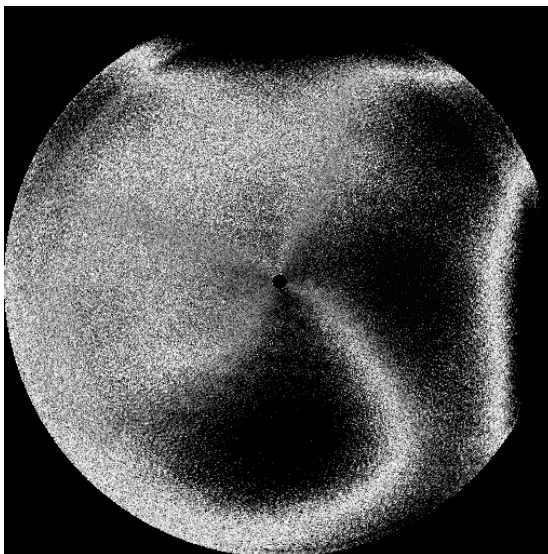
Disk 186 side 1 scan left, Filter right



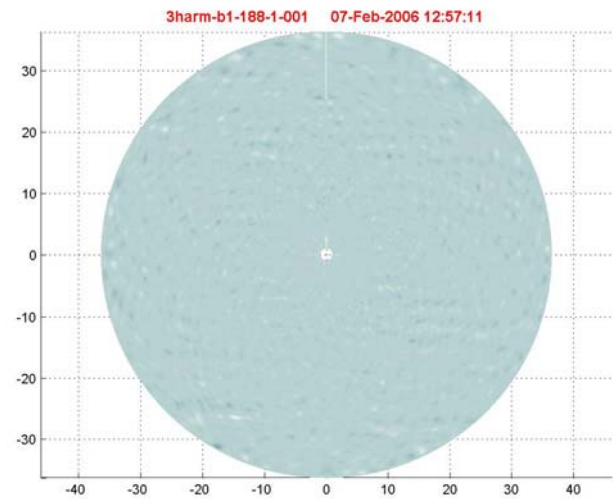
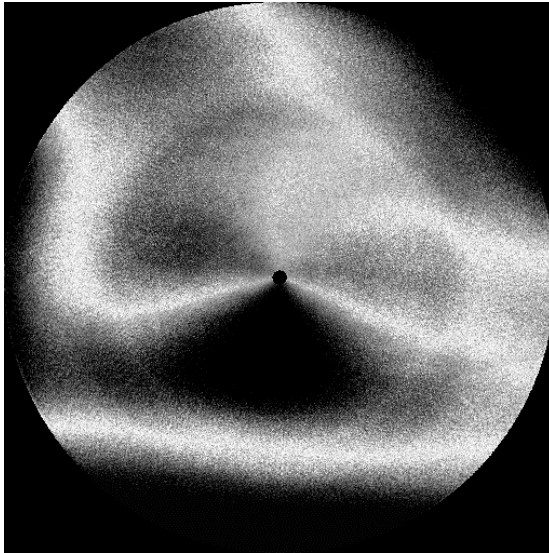
Disk 186 side 2 scan left, Filter right



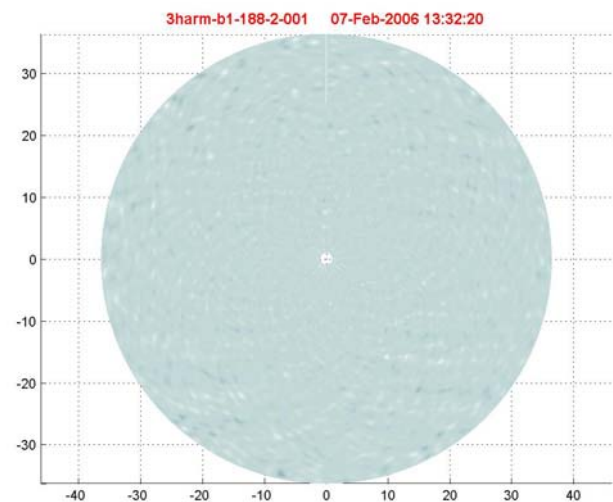
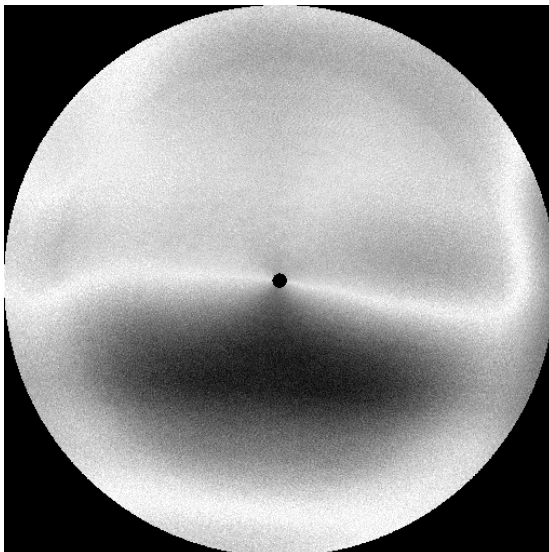
Disk 187 side 1 scan left, Filter right



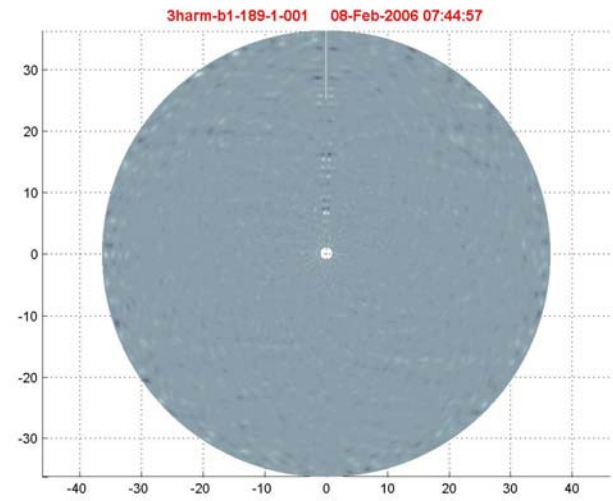
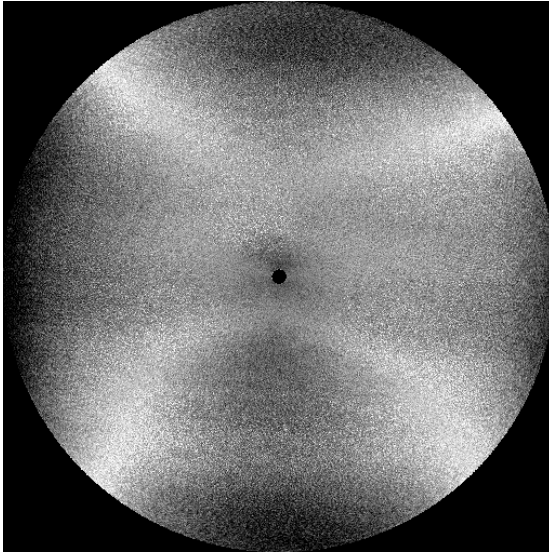
Disk 187 side 2 scan left, Filter right



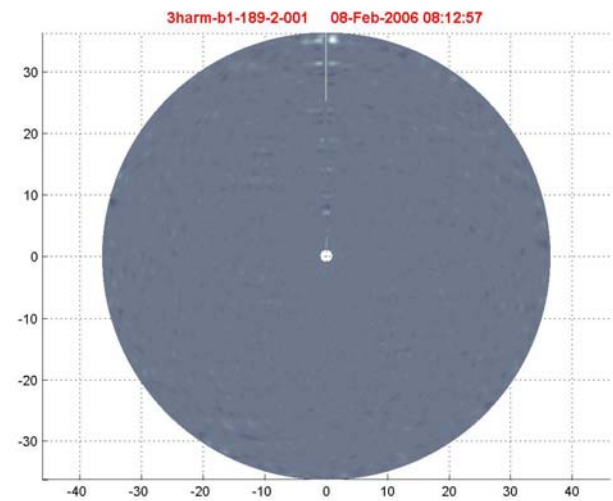
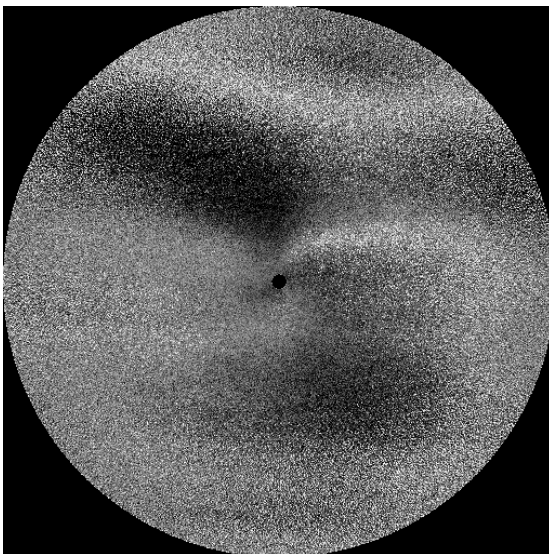
Disk 188 side 1 scan left, Filter right



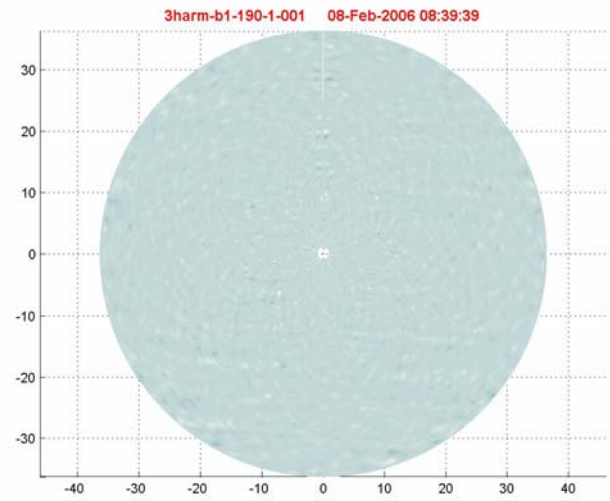
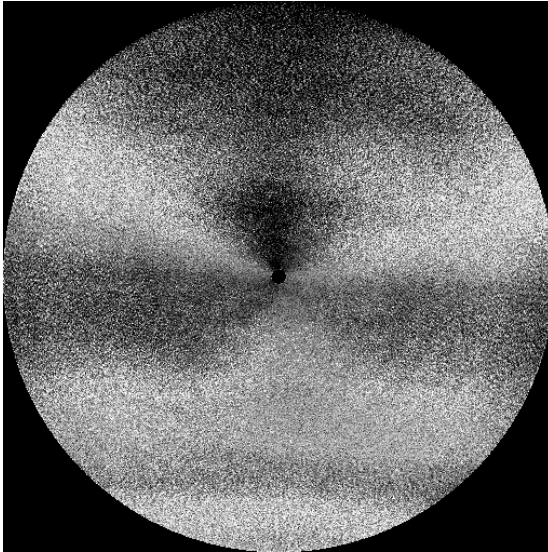
Disk 188 side 2 scan left, Filter right



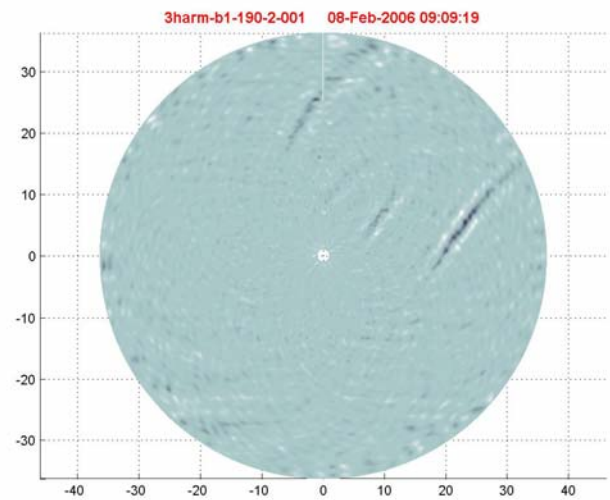
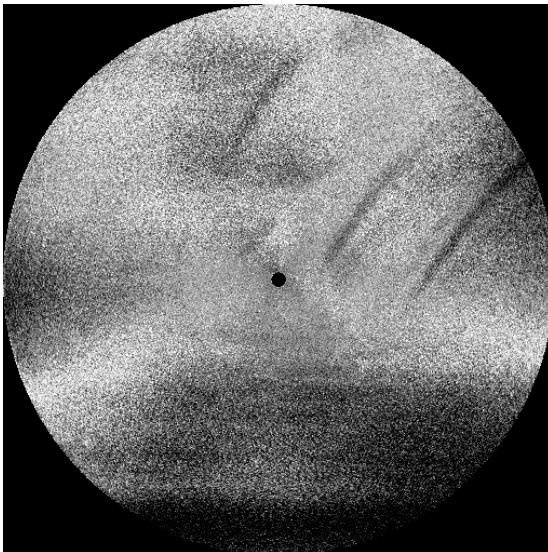
Disk 189 side1 scan left, Filter right



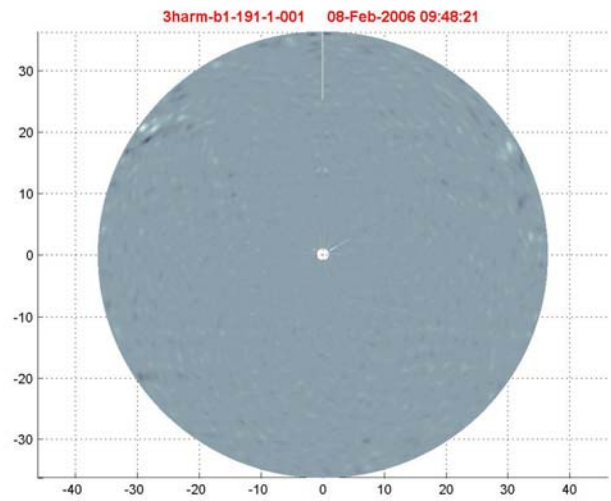
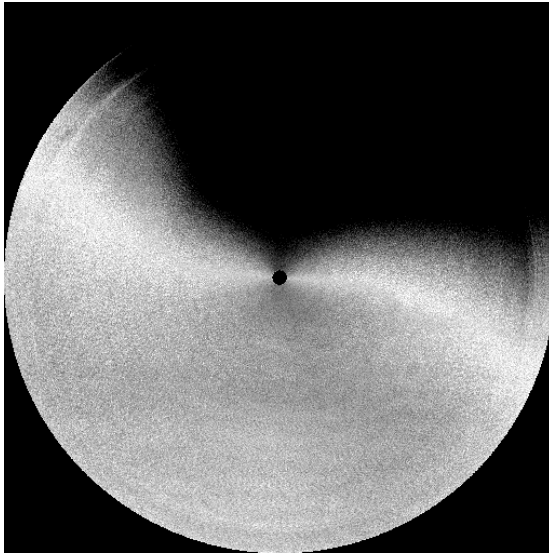
Disk 189 side 2 scan left, Filter right



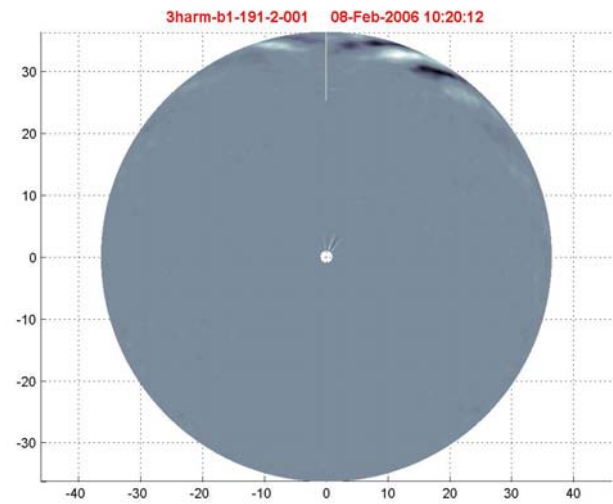
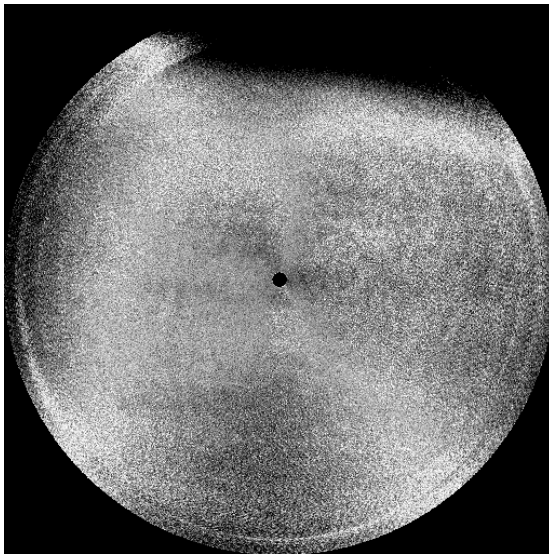
Disk 190 side 1 scan left, Filter right



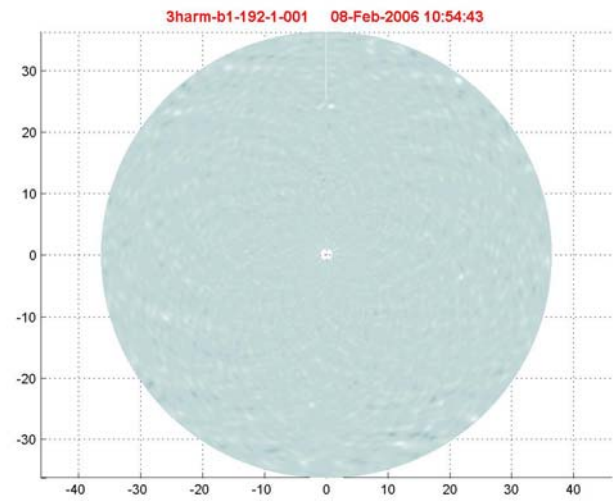
Disk 190 side 2 scan left, Filter right



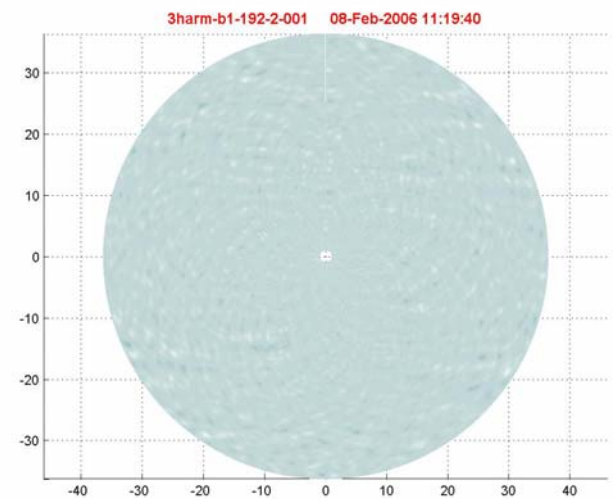
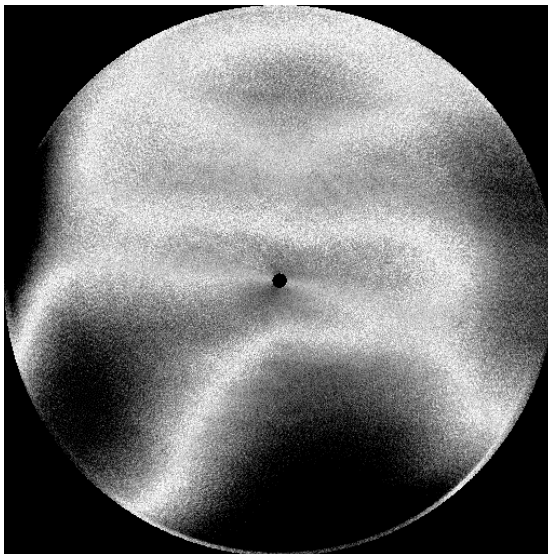
Disk 191 side 1 scan left, Filter right



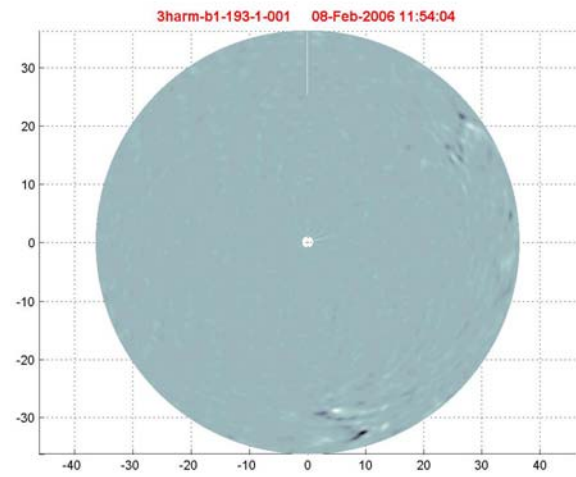
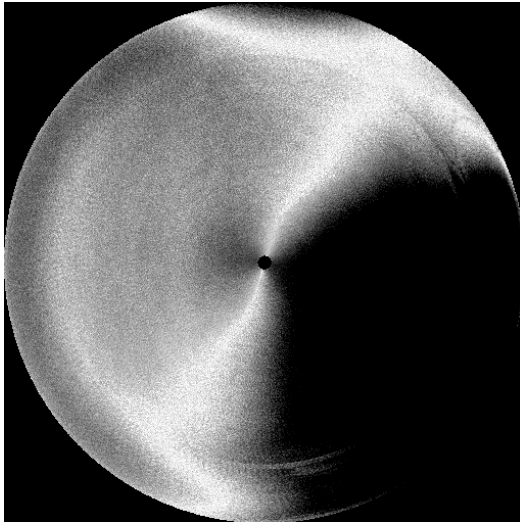
Disk 191 side 2 scan left, Filter right



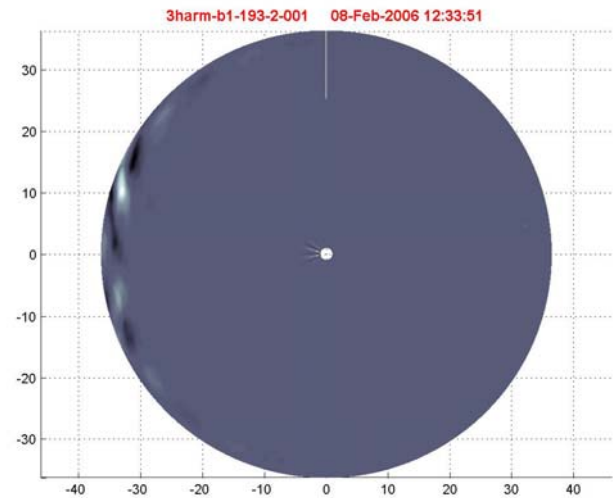
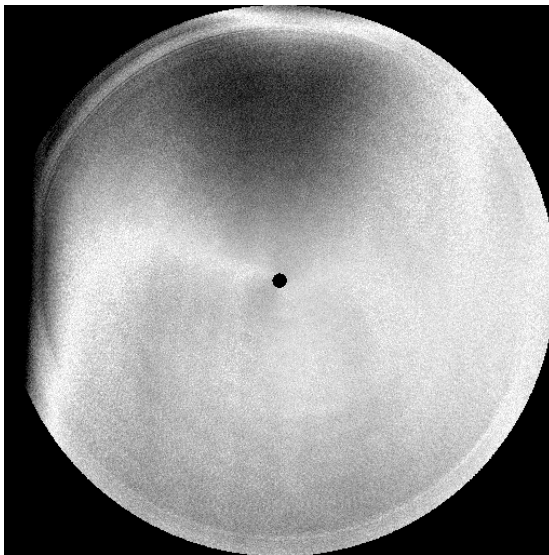
Disk 192 side 1 scan left, Filter right



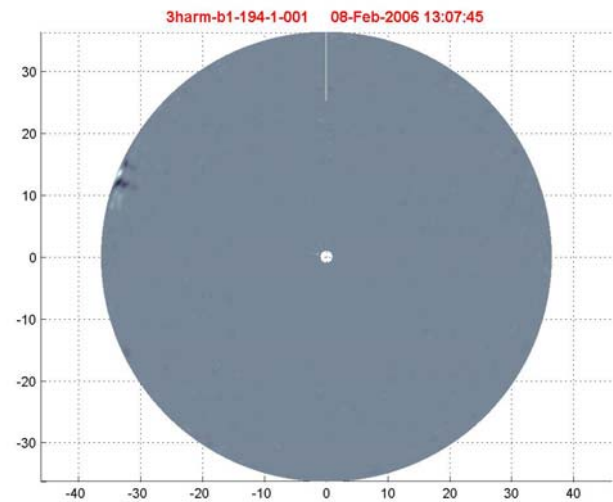
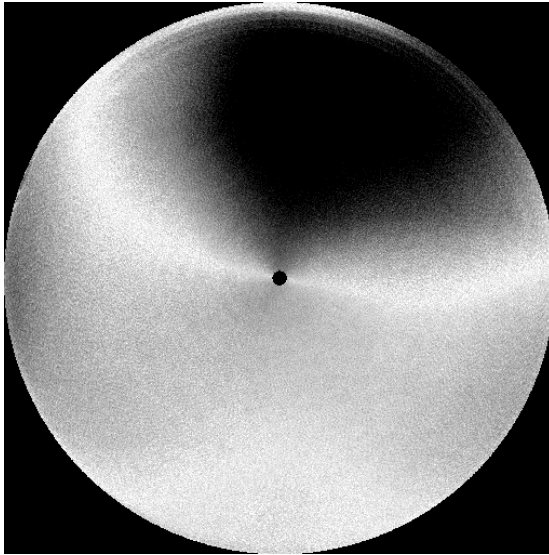
Disk 192 side 2 scan left, Filter right



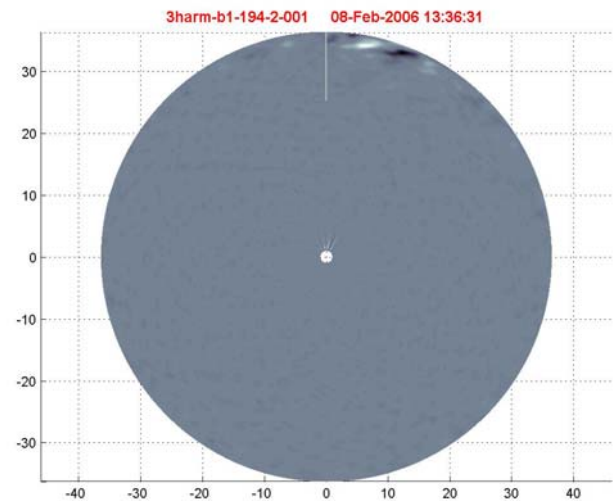
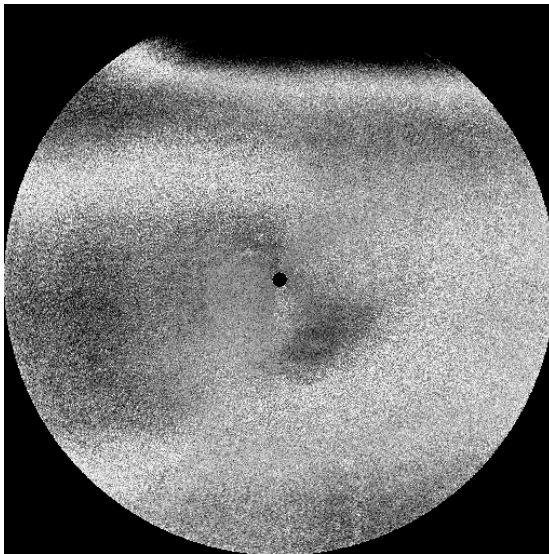
Disk 193 side 1 scan left, Filter right



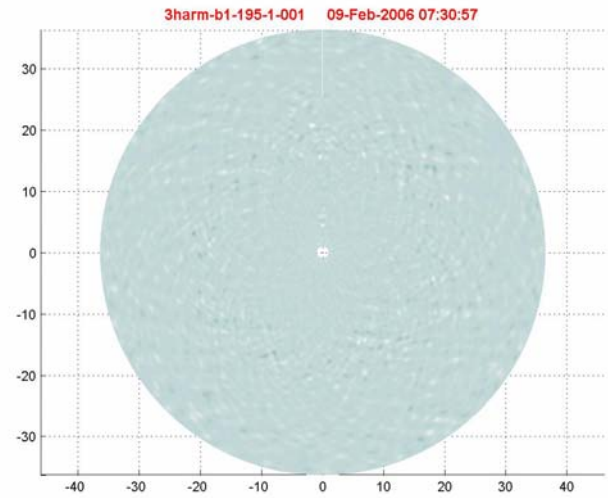
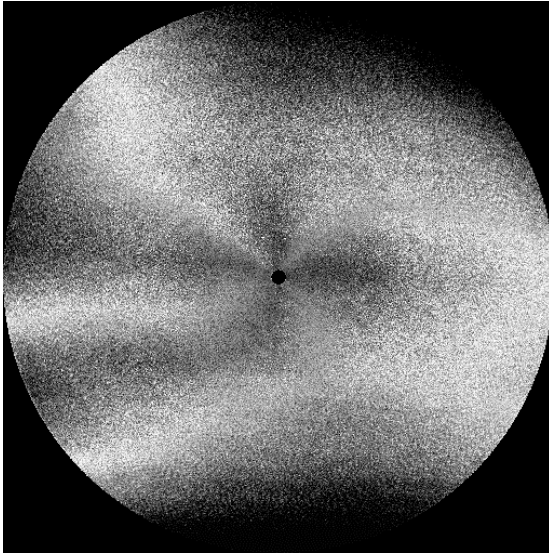
Disk 193 side 2 scan left, Filter right



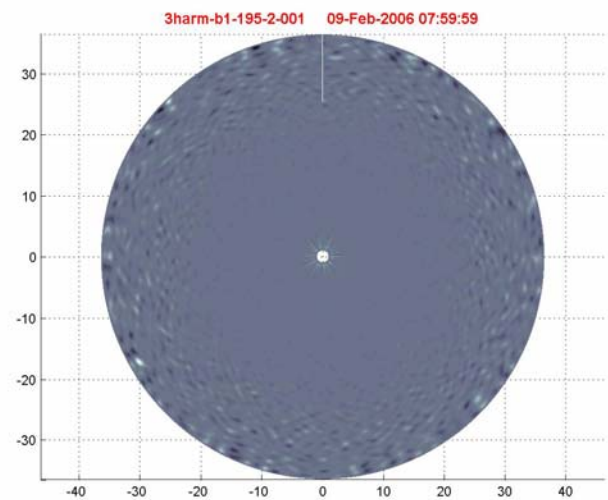
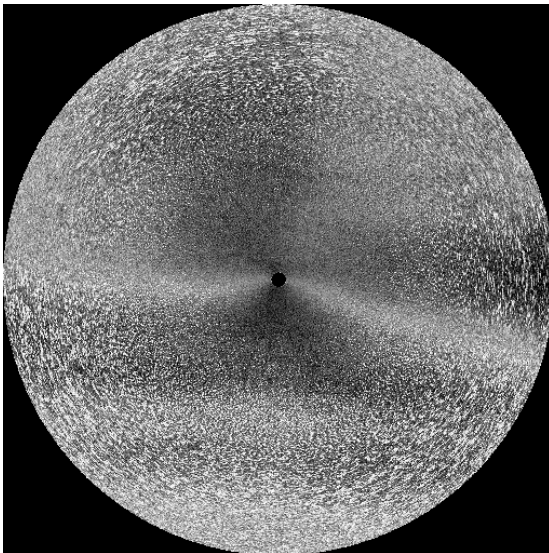
Disk 194 side 1 scan left, Filter right



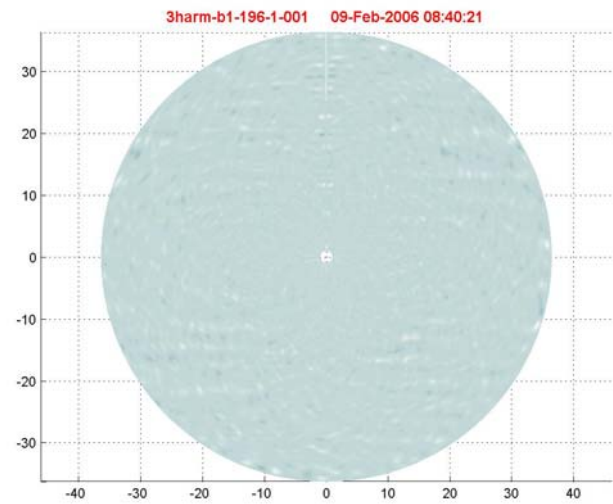
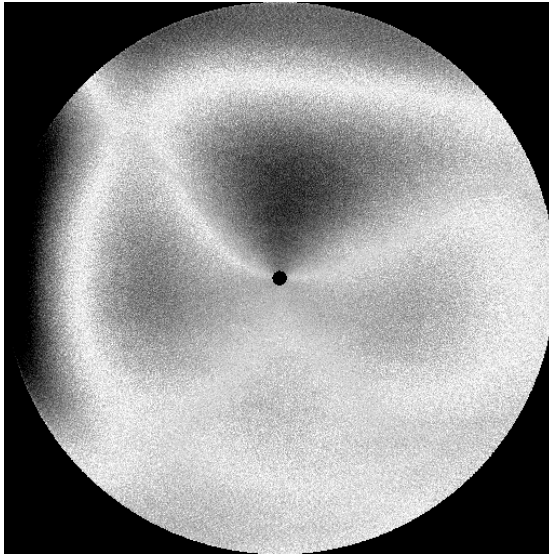
Disk 194 side 2 scan left, Filter right



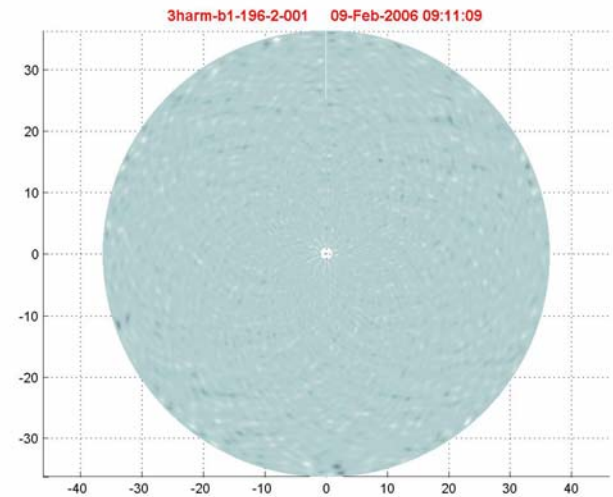
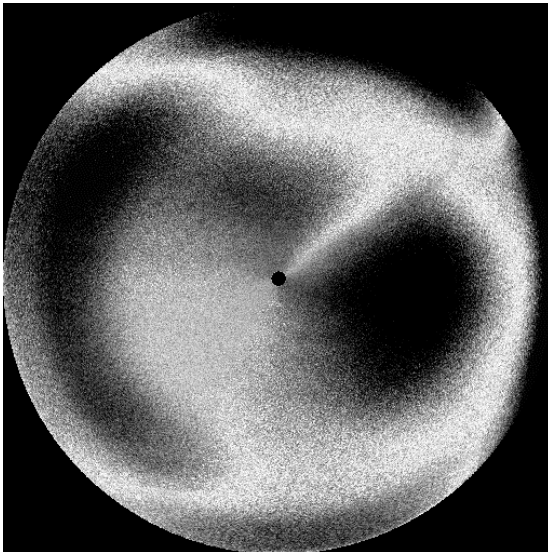
Disk 195 side 1 scan left, Filter right



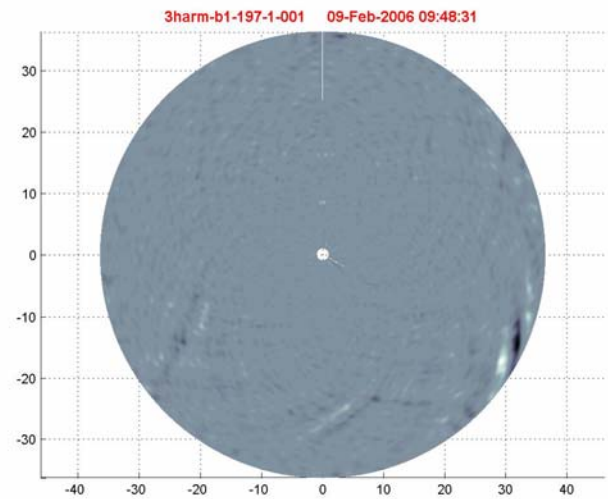
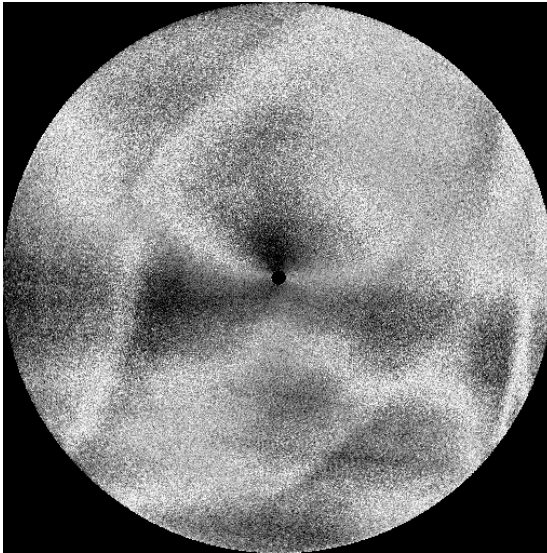
Disk 195 side 2 scan left, Filter right



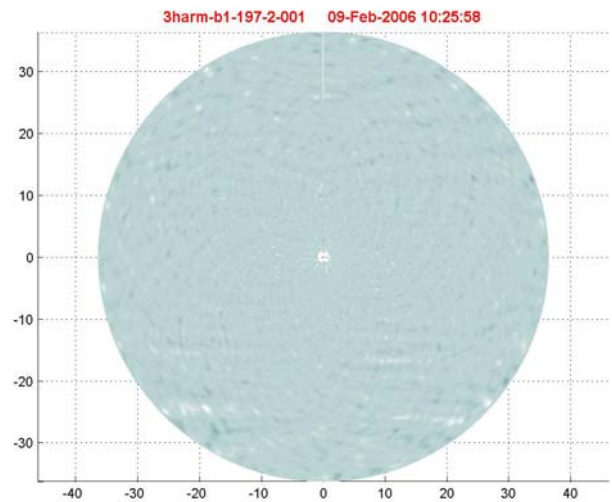
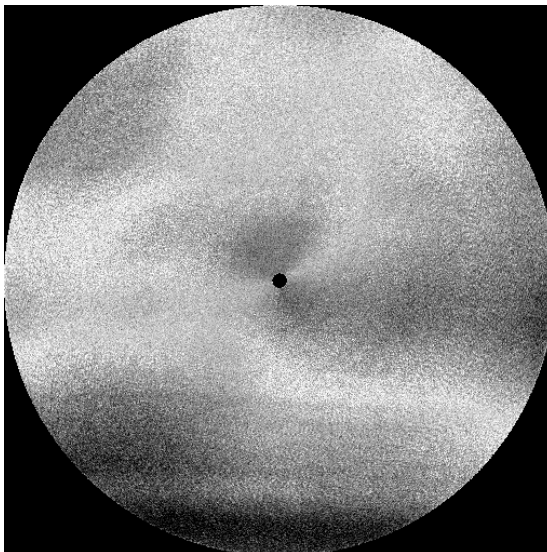
Disk 196 side 1 scan left, Filter right



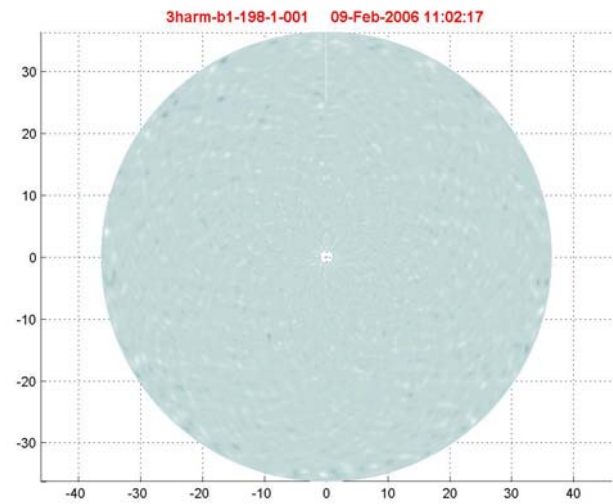
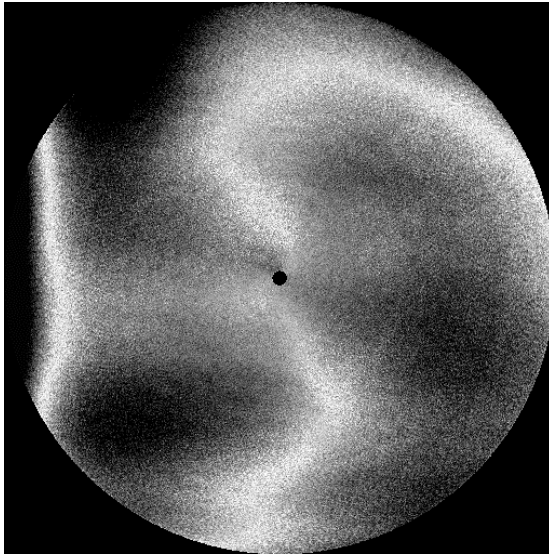
Disk 196 side 2 scan left, Filter right



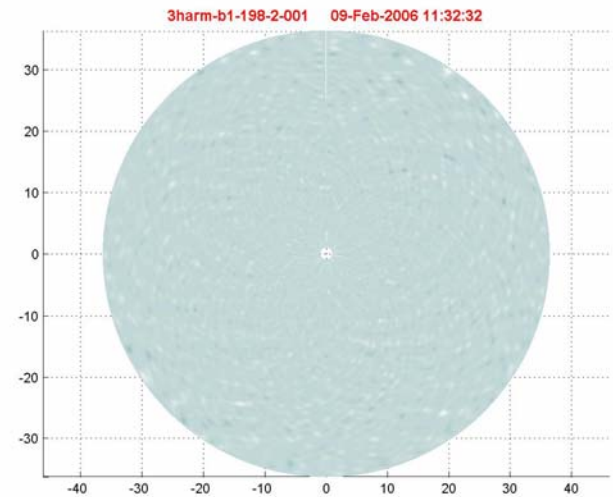
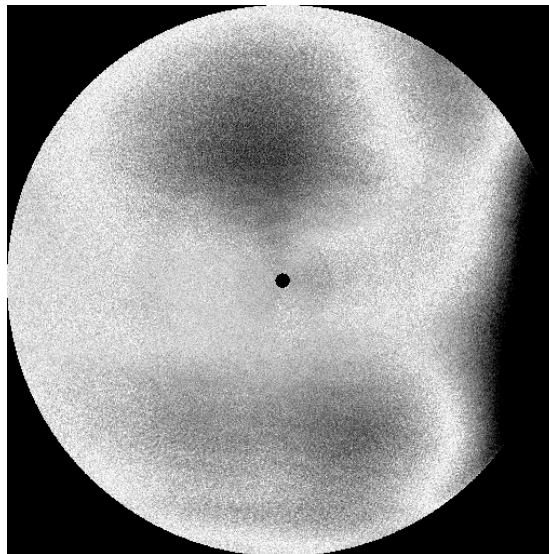
Disk 197 side 1 scan left, Filter right



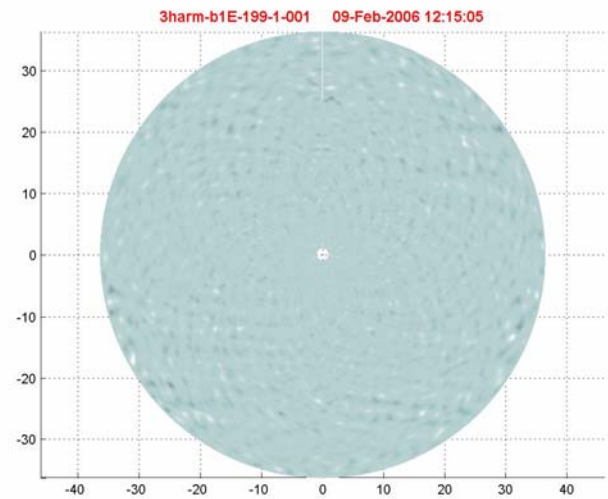
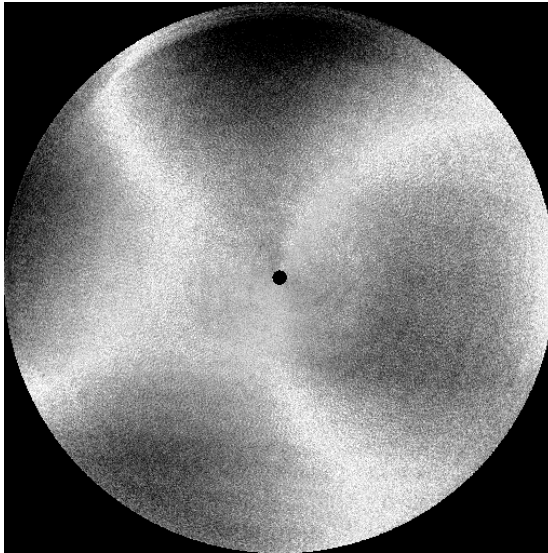
Disk 197 side 2 scan left, Filter right



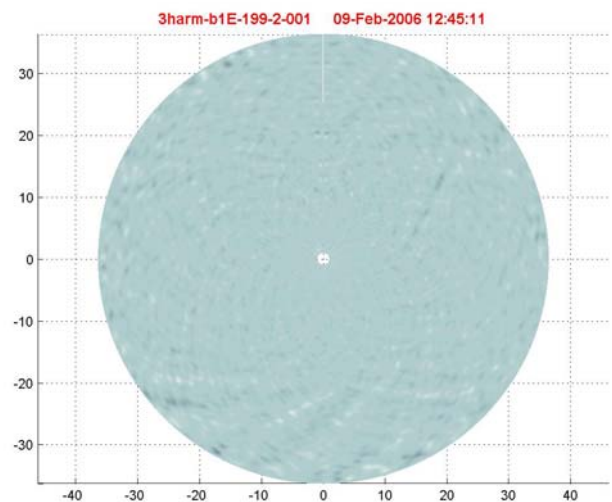
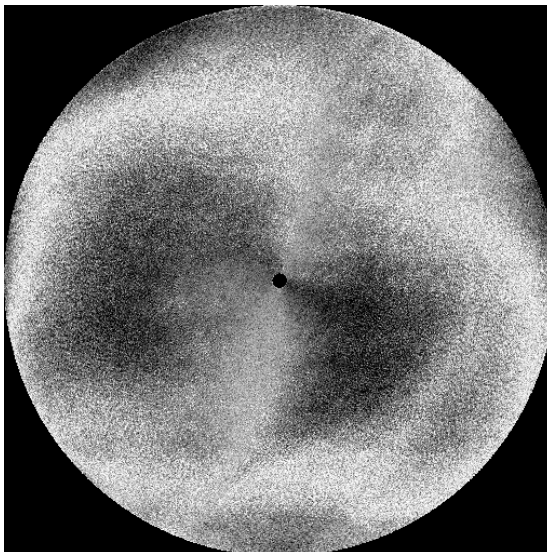
Disk 198 side 1 scan left, Filter right



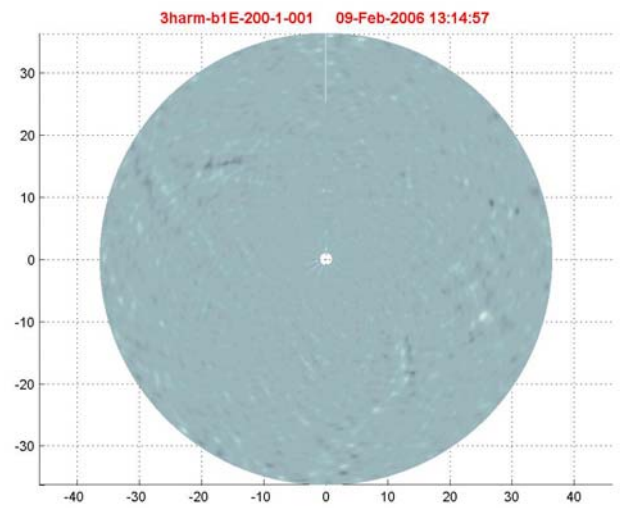
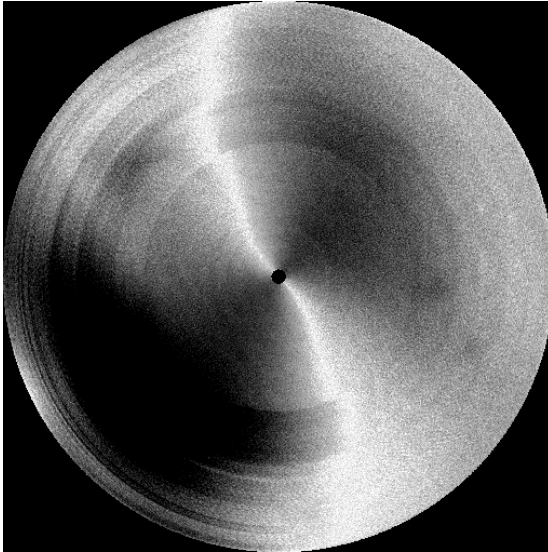
Disk 198 side 2 scan left, Filter right



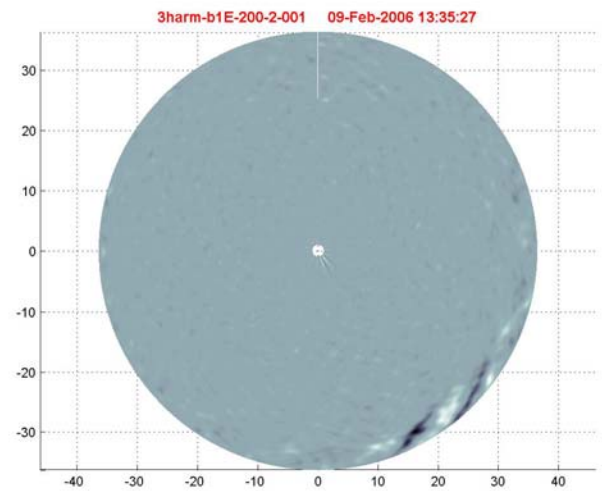
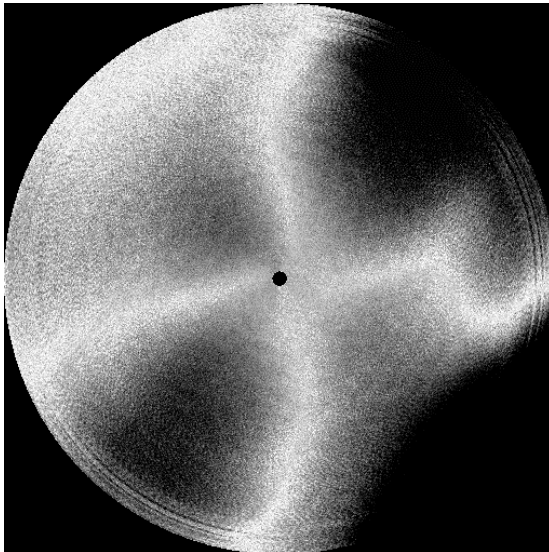
Disk 199 side 1 scan left, Filter right



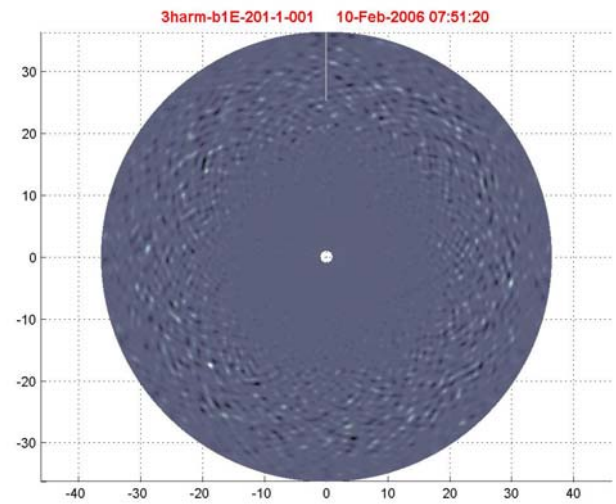
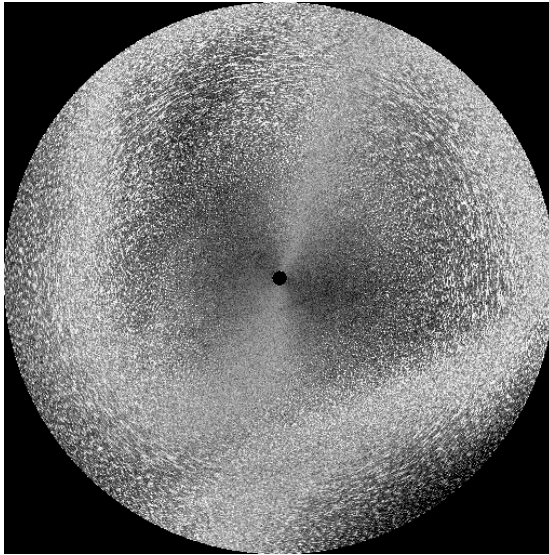
Disk 199 side 2 scan left, Filter right



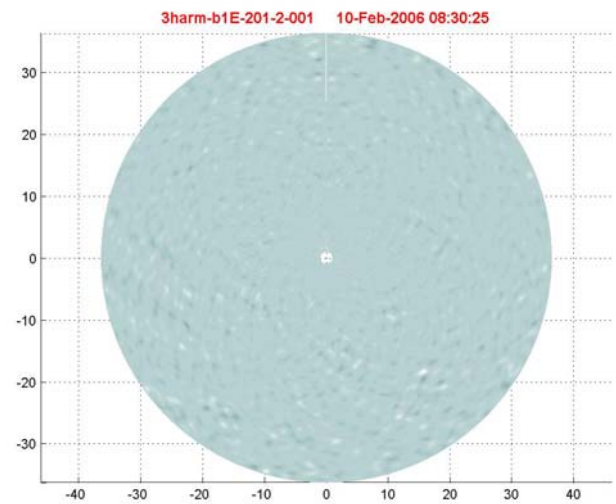
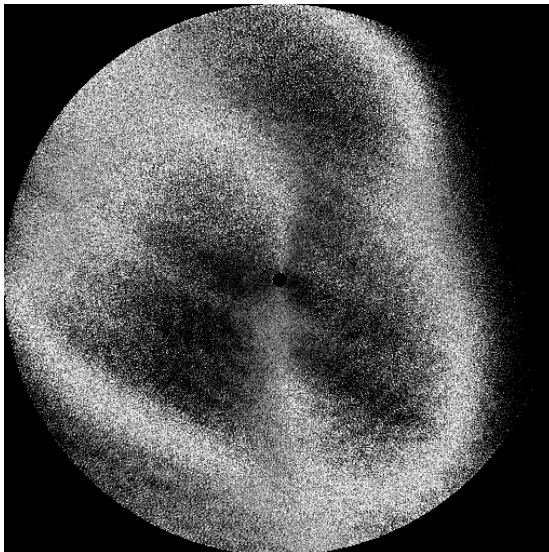
Disk 200 side 1 scan left, Filter right



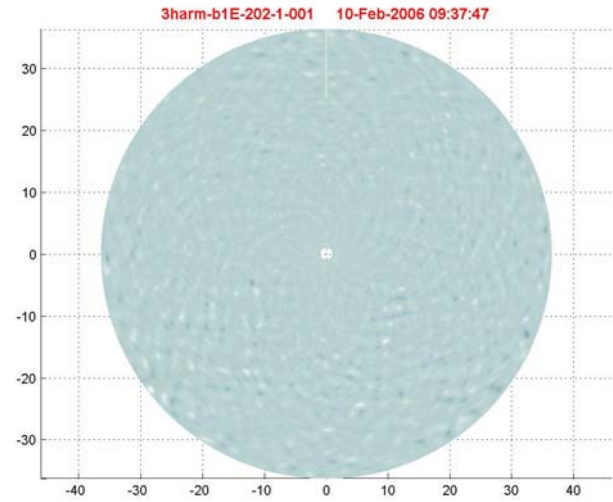
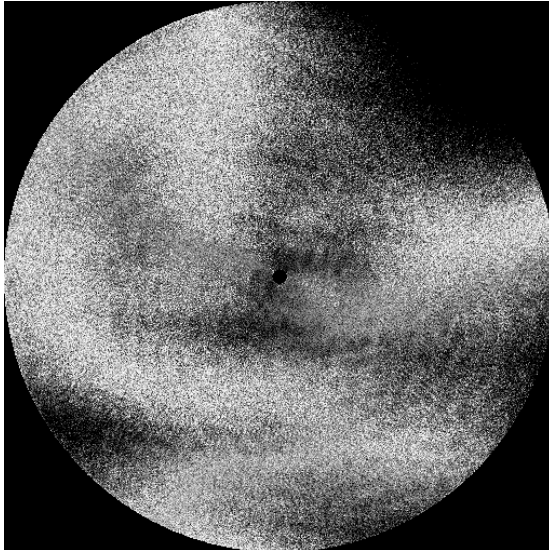
Disk 200 side 2 scan left, Filter right



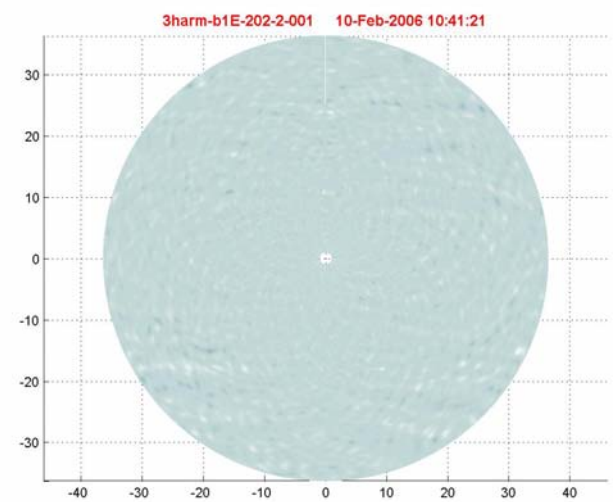
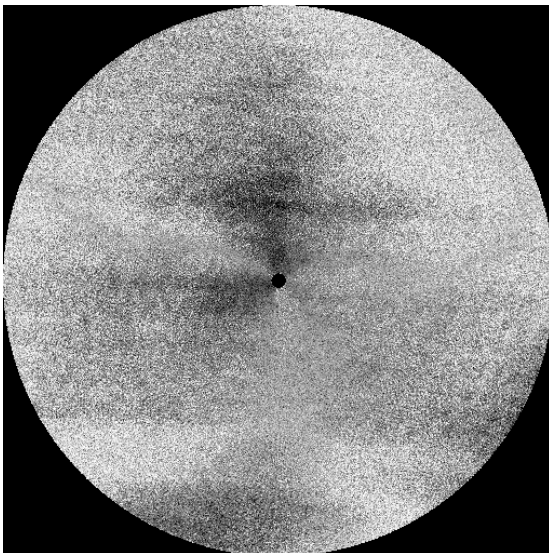
Disk 201 side 1 scan left, Filter right



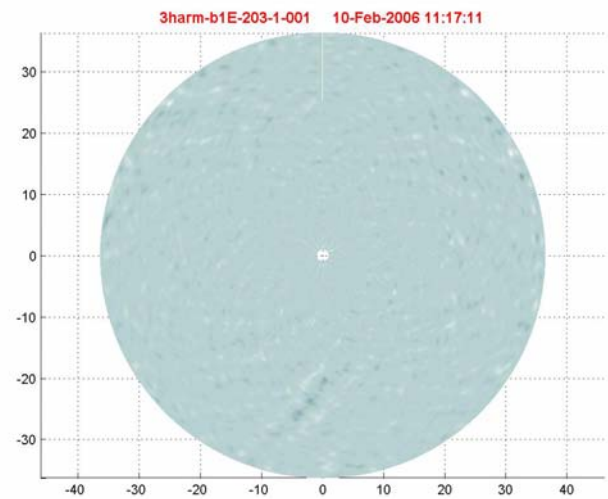
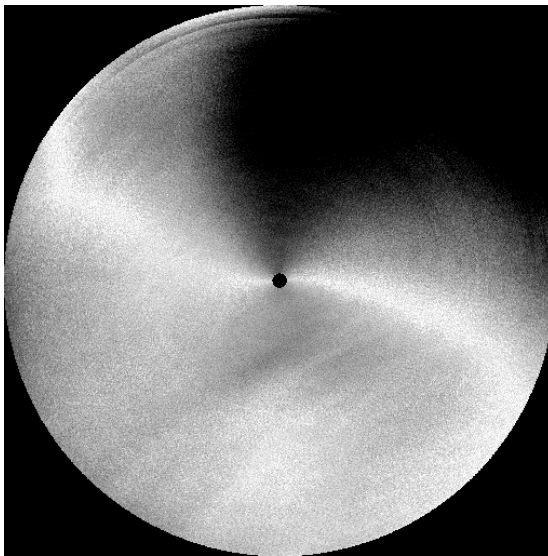
Disk 201 side 2 scan left, Filter right



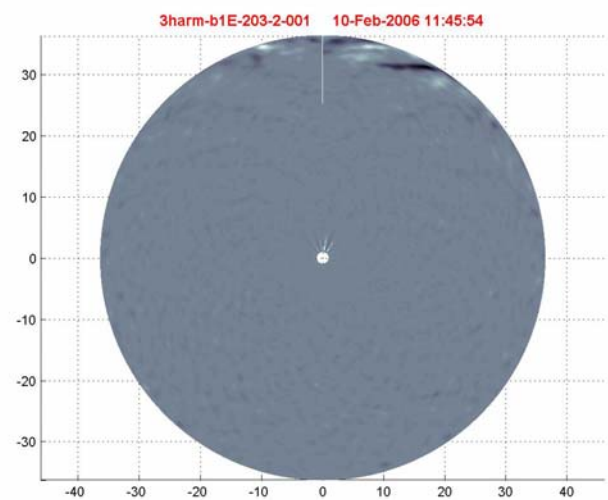
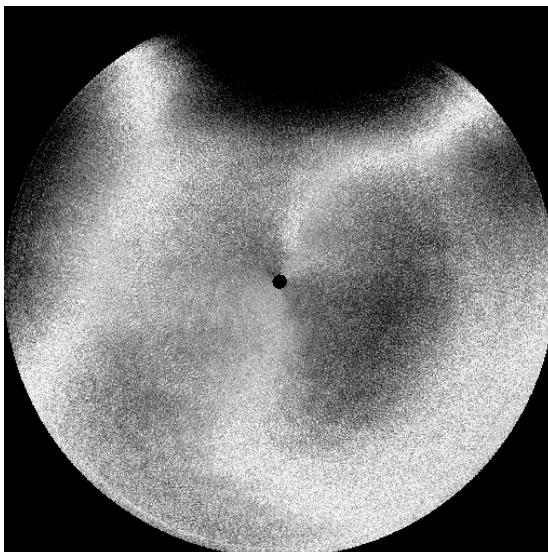
Disk 202 side 1 scan left, Filter right



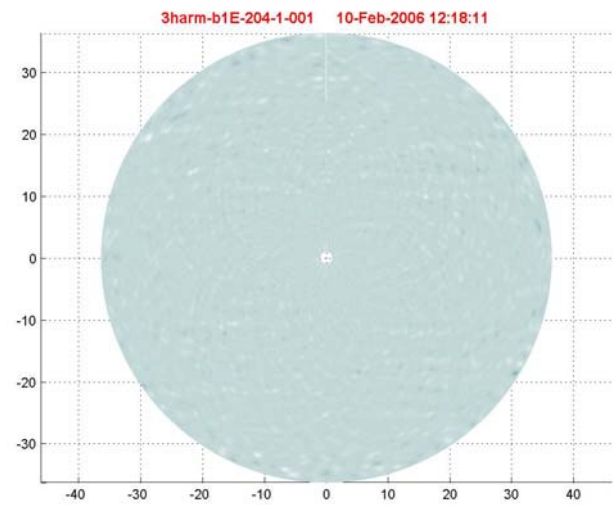
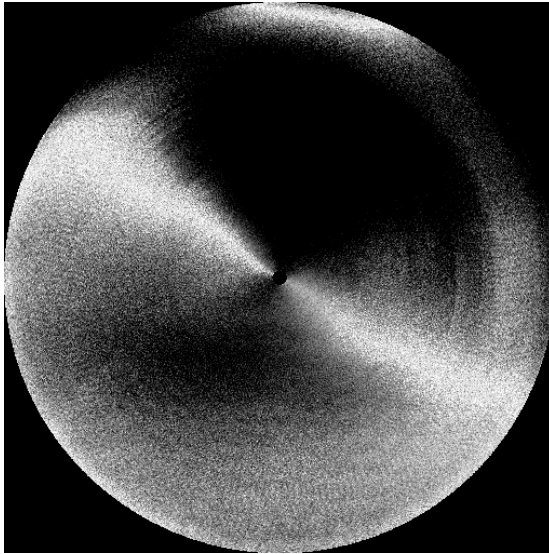
Disk 202 side 2 scan left, Filter right



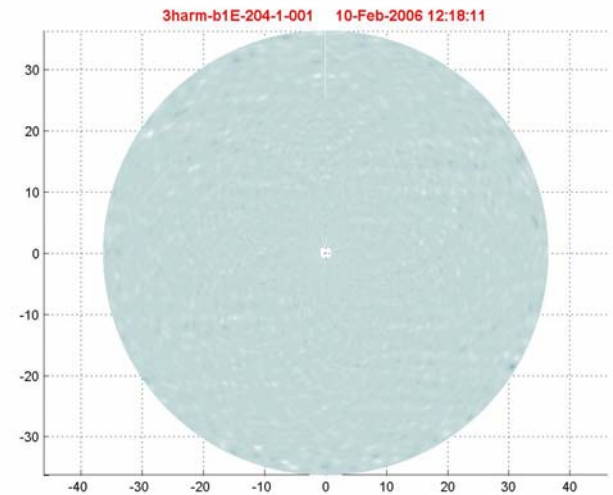
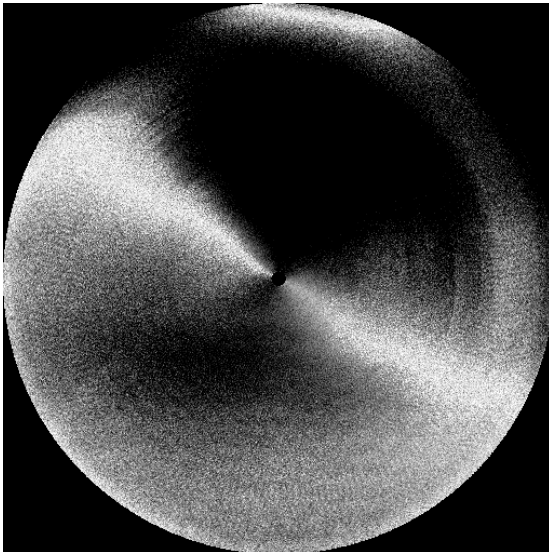
Disk 203 side 1 scan left, Filter right



Disk 203 side 2 scan left, Filter right



Disk 204 side 1 scan left, Filter right



Disk 204 side 2 scan left, Filter right

3 SUMMARY TABLES

The table below contains the results of the eddy current inspection of the 42 additional discs of the first batch of material for the FNAL third harmonic cavities. The results of a visual inspection using a simple magnifying glass are also reported. The indicated numbers are approximate angle coordinates on the discs, where the angle is counted clockwise from the 12:00 position (line-mark) on the disc. OR stands for “outer rim”, that is the ~5 mm band at the outer rim of the disc. It is to be assumed that this area will be removed during subsequent production steps. MR stands for the ring in the middle, which will also be stamped out. HR stands for “half radius” and scratches, dents and pits in this area are more serious because this area will be used in the cavities. Most of the discs are strongly oxidized along the edge as a result of the EDM cutting. This feature has not been mentioned explicitly in the table below. The last column in the table states whether the disc can be used in the cavity.

The first columns of the table indicates our recommendation as to whether the disc should be used (number in regular black) or not (**number colored red**). The disc number in the first columns is automatically red when both sides received a NO from the combined optical and ECS inspection in the last column. Furthermore a side is qualified with the **NO** label in the last column when clear signals appear in the ECS scan. The fact that the signal appears in the scanner indicates in general that the defect causing it is sufficiently large to cause concern. In the absence of a complete understanding of the nature of these “defects” we cannot categorically exclude these discs from cavity fabrication, however. We recommend that these sides are not being used for the inside surface of a cavity cell. Our different interpretations of the type of defects found are discussed in the special section at the end of this report.

disc	comment	OK ?
163	S1: A few Pits near center very small, Line (RM) through disk S2: Bad discoloration from EDM, Scratch at 220 deg. OR to MR	S1: NO S2: OK
164	S1: Lines through disk (RM) S2: Scratch near center 270 deg. OK	S1: OK S2: OK
165	S1: Light Surface Scratches, scratches at 270 deg. MR S2: Light Surface Scratches, Scratches at 5,10,250-300 deg. MR	S1: NO S2: OK
166	S1: OK S2: Lines (RM)	S1: OK S2: NO
167	S1: Burn from EDM OK S2: OK	S1: NO S2: OK
168	S1: OK S2: OK	S1: OK S2: OK
169	S1: Tiny pit near center at 95 deg. S2: Scratches through disk & dropped from Charlie Cooper	S1: OK S2: NO
170	S1: Scratch at 270 deg. MR OK S2: Small scratch at 0 deg. Close to center OK	S1: OK S2: NO
171	S1: Pit at 360 deg. MR S2: Tiny pit in center small scratch at 320 deg. OR OK	S1: NO S2: OK
172	S1: EDM burn at 350 deg. OR S2: Lines (RM) Pits at 175 & 190 MR deg. EDM burn at 10 deg. MR	S1: OK S2: OK
173	S1: EDM burn , OK S2: OK	S1: OK S2: OK
174	S1: OK S2: OK	S1: OK S2: OK
175	S1: Scratch at 0 deg. MR-OR, OK S2: Light Scratch at 340 deg. MR-OR, OK	S1: OK S2: OK
176	S1: Light Surface Scratches , OK S2: OK	S1: OK S2: OK
177	S1: Lines (RM) at 190-300 deg. MR, Scratches & pit at 270 S2: Scratch at 90-125 deg. OR	S1: NO S2: OK
178	S1: Lines (RM) S2: OK	S1: NO S2: OK
179	S1: OK S2: Nick or pit close to center OK	S1: OK S2: OK
180	S1: Black spot at 310 deg. MR S2: Pit at 130 deg. MR	S1: NO S2: OK
181	S1: Spot at 300 deg. MR, scratch at 330 deg. OR-MR S2: Scratch at 160 deg. OR, 200-220, 350 deg. MR, Nick at 220 deg. MR	S1: NO S2: NO
182	S1: Nick at 15 deg. MR S2: Nick at 95 deg. Close to center	S1: NO S2: OK

183	S1: EDM burn , OK S2: OK	S1: OK S2: OK
184	S1: Ding at 330 deg. OR OK S2: OK	S1: NO S2: OK
185	S1: Scratch at 120 deg. OR ,Tiny Pit at 175 deg. MR OK S2: Big rise at 15 deg. OR, Nick or pits at 300 deg. MR, Light surface scratches	S1: OK S2: NO
186	S1: Scratch at 95 deg. MR OK S2: Light surface scratches at 270-300 deg. MR OK	S1: OK S2: OK
187	S1: Light surface scratches from 0-180 deg. OR OK S2: Black spot at 90 deg. MR , Nick at 95 deg. MR	S1: OK S2: OK
188	S1: Light surface scratches from 0 -90 deg. MR S2: Small scratches at 210 deg. OR OK	S1: OK S2: OK
189	S1: Small scratches at 210 deg. OR OK S2: OK	S1: OK S2: OK
190	S1: OK S2: Lines (RM) 5 & 80 deg. MR	S1: NO S2: NO
191	S1: Scratch at 45 deg. OR, 270 deg. MR OK S2: Light surface scratches at 310 deg. OR	S1: OK S2: NO
192	S1: Light Surface Scratches , OK S2: Light Surface Scratches , OK	S1: OK S2: OK
193	S1: Pits at 5 & 45 MR S2: Spots at 310 deg. MR-OR	S1: OK S2: NO
194	S1: Bad scratches 350-10 deg. MR, Pits at 150, 300 MR rough edges S2: Pits at 350-360 deg. MR/OR , Pits at 270 deg. MR	S1: NO S2: NO
195	S1: Line(RM) at 90-120 deg. MR S2: OK	S1: NO S2: OK
196	S1: Pit at 300 deg. MR OR S2: Scratches and nicks at 40 deg. OR	S1: OK S2: OK
197	S1: Light surface scratches 0-90 deg. OR, Lines(RM) at 90-140 deg. MR & 220-250 S2: OK	S1: OK S2: OK
198	S1: Tiny Pit at 320 deg. MR OK S2: Light surface scratches	S1: OK S2: OK
199	S1: Scratch at 100-200 deg. MR Line (RM) 100-300 deg. MR S2: Light surface scratches, A few tiny pits OK	S1: NO S2: OK
200	S1: Pits at 35,45,270,360 deg. MR, scratches at 275 deg. MR S2: Mark from 0-160 deg. MR	S1: NO S2: OK
201	S1: Light surface scratches, OK S2: Light surface scratches, Pit at 45 deg. MR	S1: OK S2: OK
202	S1: Scratch at 160-220 deg. MR, Lines (RM) on disk S2: Light surface scratches, Scratch at 340 deg. MR	S1: OK S2: OK

203	S1: OK S2: OK	S1: OK S2: OK
204	S1: Light surface scratches, scratch at 15 deg. OR, a few pits at 180-210 deg. MR S2: (RM) 30 deg. MR & 300 deg. Area , Pit at 300 deg. MR	S1: OK S2: OK

The above table can be summarized in the following way: From the 42 discs, 21 (51%) give no signal (**OK**) and 3 discs (7%) give signals on both sides (**NO**). 17 discs (42%) have at least one side giving a signal. Most of the "signals" were found during visual inspection. These are scratches and "dings". In fact two of the three **NO** discs were rejected because of their "optical" surface appearance. Only a few sheets gave signals in the scanner. One of them is disc 190, which was also rejected. It will be discussed next.

4 SPECIAL MEASUREMENTS

Disc 190 shows very particular types of signals on side 2. Interestingly these signals can be correlated with areas on the disc with a reflectivity that is different from the rest of the disc. Further analysis could not be performed because of a lack of time.

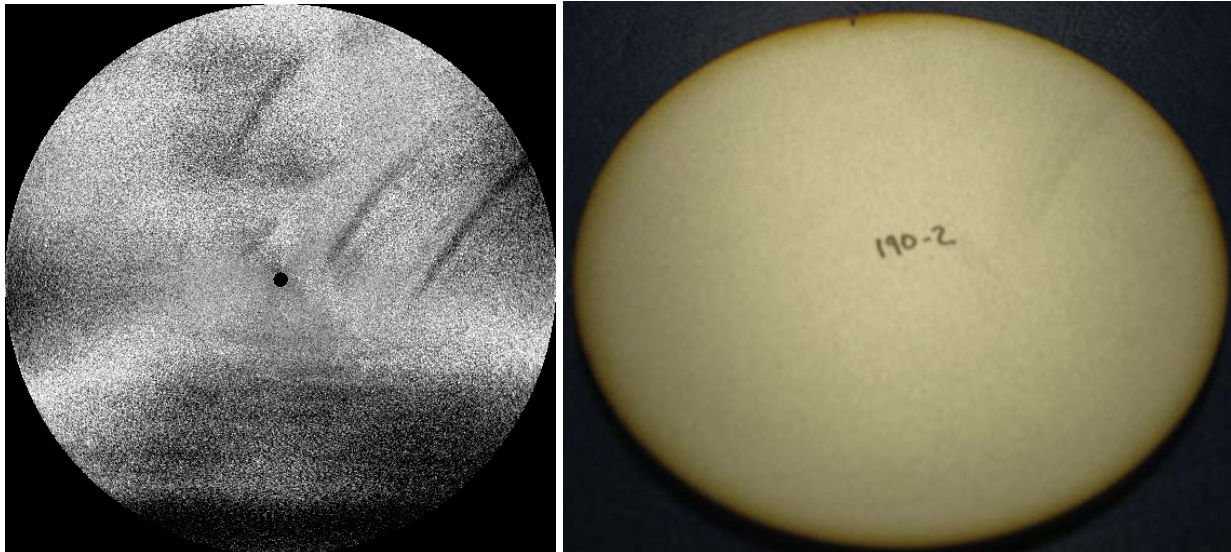


Figure 3: Eddy current scan (left) and photograph of disc 190-2.

5 SUMMARY

All 42 3rd harmonic discs discussed in this report were scanned with the SNS/FNAL eddy-current scanner and visually inspected. Defect-signals were found on both sides in **7%** of the discs. **51%** discs had no defect on any side. **42%** discs had a problem on at least one side. The typical defects found are surface scratches (mostly shallow and mostly detected visually) and “roller marks” (detected with the eddy current method only). Many of these surface defects may well be removed by the typical surface processing applied during cavity fabrication. We recommend, however, that the sides labeled with **NO** in the last column of the table not be used as the inside surfaces in the cavities. Three discs (181, 190, 194) were found to be in sufficiently bad surface condition to remove them from the batch. Disc 190, one of those removed from the batch, showed a peculiar type of defect that is not yet understood.